ELECTROCHEMICAL MODIFICATION OF GRANULAR ACTIVATED CARBON AND CARBON NANOFIBERS TO DETERMINE EFFECT ON ADSORPTION

THESIS

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Abstract

Granular activated carbon and carbon nanofiber samples were tested as is and electrochemically modified to determine the effect on adsorption. An electrochemical cell was used to modify the carbon samples. The samples were then used in bench bottle tests with 2,4-dinitrotoluene (DNT), brilliant blue (BB) dye, and methylene blue (MB) dye solutions and sampled over time intervals. An ultraviolet–visible spectrophotometer was used to analyze the results of the bottle bench tests. The results indicated that electrochemically modified coal-based carbons' adsorption were improved 25% over the adsorption of the as is carbon samples prior to modification. The electrochemical modification increased adsorption of contaminants (DNT, BB, and MB) of the three coal-based carbons at two levels of carbon concentration (25 mg and 12.5 mg). The modified carbon nanofiber showed no change in the pilot BB dye adsorption study; therefore, only scanning electron microscope (SEM) images were taken and no further BB and MB dye or DNT studies were pursued. The modified coconut shell carbon adsorption results varied in the initial DNT studies. Further adsorption studies were conducted with coconut-based carbon after electrochemical modification. The results showed that the electrochemical treatment degraded the adsorption of the coconut-based carbon below 50% of the original, as is carbon adsorption. The study further revealed over 7 days after the modification of the coconut carbon, it slowly began to regain its original adsorption performance.

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I. Introduction

General Issue

Levels of contaminants found in water after water treatments, such as aerobic or anaerobic treatment, has highlighted the need to improve remediation technologies. Secondary treatments, such as activated carbon, have been used to further remove contaminants in wastewater and other water sources (Gokce, et al., 2014). Activated carbon does, however, have its limits due to its cost in purchasing activated carbon and disposing or regeneration of saturated activated carbon. As new contaminants of emerging concern (CEC) continue to be detected, for example, products used on a daily basis, such as pharmaceuticals and personal care products (PPCPs), continued improvement of treatments needs to be developed. A novel treatment is an attempt to enhance adsorption of current activated carbon samples through electrochemical modification.

The Department of Defense (DoD) is a large stakeholder in advancing water remediation due the contamination of past and present chemicals in water sources. Many of these chemicals were used in training, operation, and response incidents that have extensively contaminated some DoD installations (Dyson, 2018). Chemicals, such as, perfluoroalkyl and polyfluoroalkyl substances (PFAS), DNT, and other chemicals are a growing concerns. PFAS was found in aqueous film forming foam (AFFF) used as fire retardant from the 1970s until 2016 (EPA, 2018). PFAS was used in in hangars and on the flight line for incidents and more so during training operation for firefighters. DNT is

found in ammunition, propellants, and explosives. The DoD is a large consumer of ammunition and explosives, especially for training at firing, artillery and explosive ranges, has contaminated the ground water and nearby water sources (Monteil-Rivera, et al., 2004). Due to the DoD's use of such products, the contaminations from them have already left their mark on wastewater and other water sources, especially in locations near production facilities and areas where large amounts of these chemical products were used.

Water treatment facilities face major environmental challenges due to CECs and legacy harmful chemicals. Some of the largest contributors to ground water contamination are potential leaks through sewers, septic tanks, lagoons, and fate and transport of wastewater indicators. As the world continues to face water shortages, countries are having to supplement traditional water uses with novel approaches, such as irrigation with treated wastewater (Kinney, 2006). Kinney, with the help of the U.S. Geological Survey, conducted a test on soils where treated wastewater was used for irrigation and found that 19 pharmaceuticals were present in treated water. The concern with many of these emerging chemicals is, due to their stable physical and chemical properties, they are persistent in nature. The complete removal of the chemicals from water has proven to be difficult. For example, PFAS chemicals found in AFFF are manmade chemicals used as surfactants, which make them partly hydrophilic, harder to remove, and persistent in the environment (McCleaf, et al., 2017). DNT, like PFAS, is structurally stable and has a low volatility, making it a candidate for underground water contamination due to its solubility (Oh, et al., 2010).

PFASs, due to their chemical structure, are stable; therefore, they do not naturally degrade easily. PFAS consist of many chemicals, two of the most produced were

perfluorooctanoic acid (PFOA) and perfluorooctanesulfonic acid (PFOS), which have been and continue to be studied. PFOA and PFOS are a concern in many municipal and federal water treatment facilities due to exceeded contamination levels in the water sources. The United States Environmental Protection Agency (EPA) has established methods to measure 14 varying PFAS compounds in drinking water to include PFOA and PFOS. In 2016, the EPA issued a lifetime health advisory limit for PFOA and PFOS in water to 70 parts per trillion due to industrial production water runoff and the uses of products, such as firefighting foams. High levels of contamination led to the EPA creating direct support for 10 states that showed an excessive PFOA and PFOS levels in underground water.

Existing contaminants, such as 2,4-dinitrotoluene (DNT), and dyes have been detected in wastewater and other water sources. These contaminants can come from the production, use, and disposal of the products. As the products are used and disposed of, they leach through the soil, becoming an issue for municipal water treatment facilities and overall water in the environment. DNT has largely been used in the manufacturing of ammunitions to include explosives and smokeless powder. Contamination from DNT has been found at locations near manufacturing plants, munitions training centers, and explosive ranges. Its presence in water is expected to remain for long periods of time due to its low volatility and its solubility in water (EPA, 2017). In 2016, the EPA identified 56 sites where DNT had reached levels of concern. Sites consisted of areas where munitions were manufactured and previous firing and explosive training ranges.

After multiple EPA studies, they determined that exposure to DNT in drinking water should not exceed levels of 1 mg/L. Health effects of DNT found in laboratory animals have ranged from nervous system disruption (signs of neurotoxicity, tremors, limb

weakness, and convulsions) to being carcinogenic (hepatic tumor, liver, lung, gallbladder, kidney and connective tissue cancers) (EPA, 2008). Animals also showed adverse reproductive effects such as testicular atrophy, decreased spermatogenesis, and fetal deformities. Inhalation exposure to DNT in occupational environmental studies caused health effects ranging from dizziness, headaches, and tingling in the extremities. Furthermore, DNT is listed as a toxic substance under Section 313 of the Emergency Planning and Community Right to Know Act (EPCRA). Any spills or disposal of 10 pounds or more of DNT must also be reported and tracked as part of the Comprehensive Environment Response, Compensation, and Liability Act (CERCLA) in order to reduce likelihood of exposure and contamination.

Dyes can be found in almost everything we use on a daily basis. The textile industry is a leading consumer of dyes, creating a large amount of wastewater from dye baths, washing, and rinsing of products (Faria, 2004; Wang, 2006). Though various types of dyes exist, many have been limited to certain uses due to related allergic reactions and other health effects. Health and safety concerns with dyes vary depending on concentrations and types of dyes, including irritation, dermatitis, and blindness in some instances (FDA, 2018; Madsen, 2015; Malinauskiene, 2011). In some severe cases, multiple dyes have been found to be mutagenic and carcinogenic to human beings (EPA, 2010). Environmental impact of dye contamination can also negatively affect aquatic life because of reduced sunlight through water (Salleh, et al., 2011).

Statement of the Problem

Contaminants such as DNT, and BB and MB dyes have been found in groundwater and other sources of water (Jiménez-Tototzintle, 2018; Gao, 2012; Monteil-Rivera, 2004). The most common method to mitigate contamination has been the pump-and-treat process using adsorption to remove contaminants (Ma, et al., 2017). Adsorbents such as carbon, and more specifically granular activated carbon (GAC), have been found to partially remove such contaminants. This research used carbon nanofibers (CNF) and multiple GACs as is, and modified, to determine if electrochemical surface modification could enhance adsorption capabilities similar to chemical modification (Wang, 2006, Yang et al., 2015). Calgon Filtrasorb ® 600 (F600), Evoqua AquaCarb® 1230CXPB55, Evoqua UltraCarb® 1240AW, NORIT GAC 400 GAC, and Applied Sciences Inc. PR-25-XT-PS CNFs were used with BB and MB dye and DNT to determine before and after modification adsorption capabilities.

Previous work from Schmidt (2017) found that introduction of PFAS in effluent wastewater treatment decreased the total adsorption of GAC due to the over saturation from total organic carbon (TOC). This was due to what Schmidt suggests as the higher attraction of TOCs versus PFASs to the GAC pore structure. Continued work by Dyson (2018) furthered the knowledge of PFAS adsorption by introducing advanced oxidation process (AOP) prior to GAC treatment to reduce TOC concentration. Dyson found that with the introduction of AOP to a treatment system, the GAC would have less contaminants competing for adsorption. Further, establishing a need to enhance the adsorption of GAC to limit the need for other costly pretreatments.

GAC research has shown that it is capable of reducing CECs, DNT, and dyes (Chen, 2011; EPA, 2018). The activation of carbon has been accomplished through various means such as thermal, physical, and chemical processes to enhance their adsorption capabilities (Bhatnagar, 2013). Electrochemical activation research has mostly remained as a means to modify carbon for enhancing electrical properties of carbon for use in electronics (Fan, 2018; Li, 2009). On the other hand, carbon activation by chemical modification with acids have been accomplished with good results. This suggests a means to assist in electrochemical modification to further enhance the adsorption capabilities through the use of acids as an electrolyte. Acid modification with nitric acid of carbon nanotube (CNT) and GAC has shown to improve contaminant adsorption capabilities (Castilla, 1995; Ihsanulla, 2016). Therefore, continued research using nitric acid as the electrolyte to improve the electrochemical modification treatment is of interest.

Methodology

The electrochemical modification of carbon species was accomplished using an electrochemical cell. An acidic solution made of nitric acid and deionized water was used as an electrolyte to assist in conducting the current through the carbon species. The method to assess the adsorption performance of the various carbon species was bench bottle testing. The sampling of solution was drawn from the bottles at set intervals to compare the contaminant removal performance of as is and modified carbons using an Ultra-Violet Spectrophotometer (UV-Vis). The results were compared to determine whether an enhancement of adsorption had occurred using the electrochemical treatment.

Research Objective/Questions

The objective of this research is to determine if an electrochemical surface modification process on carbon species can enhance the adsorption capability. An evaluation between the as is samples and the samples modified were made to determine:

Objective 1 – Study the electrochemical modification of GACs.

Hypothesis: Electrochemical modification of carbons will enhance the overall carbon adsorption.

Subtask 1.1 – Electrochemically modify carbon species for bench bottle test.

Subtask 1.2 – Assess the adsorption of DNT in bench bottle test from as is and modified carbon species using the UV-Vis.

Subtask 1.3 – Compare results to determine whether an adsorption enhancement was created.

Objective 2 – Study the cationic or anionic properties of as is and modified GACs.

Hypothesis: Electrochemical modification oxidizes the carbon, therefore, increasing the anionic adsorption properties of the GACs.

Subtask 1.1 – Perform bench bottle test using BB (anionic) and MB (cationic) dyes with as is and modified carbon species.

Subtask 1.2 –Determine adsorption of BB and MB dyes using 6 mg, 12.5 mg, and 18 mg of as is and modified GACs using the UV-Vis.

Subtask 1.3 – Compare results to determine whether a cationic or anionic adsorption enhancement was created, using BB and MB dye.

Summary

This chapter addressed the need for increasing the adsorption capabilities of carbons used in water filtration technologies. It provided the reader with the knowledge base to relate current water contamination and the need to improve the already existing carbon media used for filtration. Toxicity data for CECs, DNT, and various dyes suggests potential health concerns to humans; therefore, it is imperative to pursue effective and efficient carbon media to remove contaminants from water. This thesis is written in the traditional format where Chapter Two presents the current literature on the ongoing research in carbon to treat CECs, DNT, BB and MB dyes.

II. Literature Review

Chapter Overview

The body of research discussed in this chapter focuses primarily on CECs, DNT, dyes, water treatment techniques, and electrochemical carbon modification. CECs consist of various types of chemicals, such as persistent organic pollutants (POPs) (flame-retardants, foams, plastics, etc.), pharmaceuticals and personal care products (PPCPs), endocrine disrupting chemicals (EDCs), and nanomaterials (EPA, 2008). DNT is a chemical that has been primarily used in the production of ammunition and explosives, which has led to contaminations near manufacturing plants and areas where large use of these products have occurred (Chen, 2014; Ma, 2017). Multiple dyes have been shown to have an adverse effect on human health; therefore, as a large contributor to wastewater contamination from the textile industry and consumer goods, it is imperative to continue dye studies (Purkait, et al., 2007). Current water treatment techniques consist of various methods using, GAC, resins, reverse osmosis (RO), ozonation, and ultraviolet radiation. GAC is one of the most common forms of remediation due to its lower cost to implement; therefore, this research aims at improving commercially existing GAC through electrochemical modification (De Gisi, et al., 2016).

CECs can include multiple types of chemical compounds that have not historically had any regulatory standards. The two most common groups that CECs are categorized into are pharmaceuticals and personal care products. The concern is that PPCPs are commonly disposed of in wastewater during use and the use/disposal is prevalent in households that are not bound by the strict regulations that corporations may be required

to follow. Furthermore, the impact from low concentration in water sources to humans and aquatic life are unknown (Birch, 2005; EPA, 2008). The reason CECs are a concern are because current water treatment facilities are not able to completely remove these contaminants (Schoenfuss, et al., 2015). The occurrence of CECs in underground water comes from wastewater discharge, agricultural use, animal feeding operations, and landfill leaching (Barnes et al. 2002). Although, the long-term compounding health effects are currently unknown for many of these contaminants at low concentration they may eventually include adverse effects.

The large concern of CECs are the altering effects not yet known to include fate and transport of these chemicals in underground water. Antibiotic residuals are a concern as they are one of the most commonly prescribed medicines for illnesses in humans, livestock and plants worldwide (Baran, 2018; Nariyan, 2017). Research has shown that bacteria and animals exposed to low concentration of antibiotics can develop resistance to those antibiotics creating a problem with future treatment effectiveness (Witte, 1998; Kinney, 2006). Witte also noted that exposure from eating meats where animals were given antibiotics used in immunotherapy as growth promotors created various resistance to antibiotic treatment.

An estimated 30,000 kg/yr of natural estrogens and over 700 kg/yr of synthetic estrogens are released (Adeel et al. 2016). Studies have found that many of these chemicals in PPCPs, and more exclusively endocrine disrupting compounds (EDCs), contain estrogens that are designed to stimulate the physiological response in humans and animals (Daughton 1999; Aris 2014). Studies found that at low concentration of these chemicals, presence of both male and female characteristics were found in fish downstream from water

treatment facilities (Adeel 2016; Joplin 2008; Woodling 2006,). Kinney's study further found in 2007 that a synthetic estrogen, ethynylestradiol (EE2), caused reproductive failure of fathead minnows, reducing the population during a multiyear study.

DNT is a manmade chemical used in the production of polyurethane foam, ammunition, explosives, and dyes (EPA, 2000; EPA, 2012). DNT has been found in 98 sites of the 1,699 current National Priorities List (NPL) sites as of 2016 (U.S. Department of Health and Human Services, 2016). This refers to only the sites that have been tested for DNT; therefore, further investigation of other potential sites could identify additional contaminated areas. DNT has been found in water in various locations, bays, rivers, and underground water (Kuo, et al., 2017). DNT has commonly been found in areas where DNT by-products are manufactured, as well as areas where a large amounts of ammunitions and explosives have been used (Clausen, 2011; EPA, 2012). For example, past water samples in the Potomac River near Quantico, VA were found to have < 10 μg/L (Hall et al., 1987) and the Waconda Bay in TN ranging from <.10-22.1 μg/L (Putnam et al., 1981).

Negative health effects from exposure to DNT depend on concentration, duration, and route of exposure. Chronic oral exposure to DNT has been found to have adverse effects to the liver, kidney and blood (EPA, 2005). In laboratory studies using rats, DNT was found to promote tumors; therefore, it is classified as a 2B "possible carcinogenic" to humans (IARC, 1996). The lab studies of rats found that most developed cancer in the liver and tumors in the kidney (Dent, 1982; Mori, 1989). This led to the EPA setting a minimum risk level of 2 μg kg $bw^{-1}day^{-1}$ based on oral exposure to dogs after a study published in 1992.

Dye water contamination is common due to the high demand in the textile industry (Gupta, et al., 2009). Commercial dye classification largely consists of cationic, anionic and nonionic dyes (Salleh, et al., 2011). BB (anionic) and MB (cationic) dyes are commonly used as surrogates for other dyes and chemicals with similar chemical structures in research (Hameed, 2009). Anionic dyes carry a negative charge where cationic dyes carry a positive. Dye contamination in water sources can negatively affect aquatic and human life. Multiple dyes have been found to be carcinogenic or mutagenic as worst-case scenarios as well as causing temporary adverse effects such as allergic dermatitis and skin irritation (Hazzaa, et al., 2015). BB dye research has found BB to have adverse health effects such as carcinogenic and create adverse reproductive and neurological disorders (Gupta, et al., 2005). MB dye in general can cause irritation on the skin, eye burning, nausea, vomiting, and diarrhea if swallowed as well as mental confusion if inhaled in large quantities (Tan, et al., 2008). Furthermore, using BB and MB dye as surrogate contaminants in the study of electrochemical modification of carbon are worthy comparison to other complex organic chemicals that may possibly fall under the CEC umbrella.

CECs, DNT, and dyes have been found in waste streams that have led to contamination of surface and underground water sources. CEC removal from water sources can vary depending on variables such as biodegradation, sorption, aeration, pH and temperatures (Krzeminski, et al., 2018). The known degradation pathways of many CECs is still limited due to the thousands of chemicals found under the CEC umbrella. For example, DNT, due to its chemical structure, it has relatively low volatility and moderate water solubility (270 gm/L at 22°C), which make it persistent in water (Jenkins et al., 1986

and Sigma Aldrich, 2018). The removal of DNT is difficult due to electron withdrawing nitro groups, making adsorption treatment a better option (Achtrich C. 1999; Ma, Z. 2017).

CEC, DNT, and Dye Presence in the Environment

CECs are predominantly found near product manufacturing plants and locations of the products' use. Due to the common use of CECs, this has become a main concern for many wastewater treatment facilities. Wastewater treatment facilities were not originally designed for removal of these contaminants, therefore; CEC contamination continues to be an issue post treatment (Kinney, 2005). Studies have found concentrations of multiple CECs worldwide in wastewater after treatment. Gao (2012) found levels of various PPCPs such as sulfamethoxazole at 1566 ngL^{-1} in raw influent and 178 ngL^{-1} in final effluent after treatment in a Michigan treatment facility. Other countries concentration of sampled post-treated wastewater found 7190 ngL^{-1} and 820 ngL^{-1} of sulfamethoxazole in in China and Germany, respectively (Pengs, 2006; Ternes, 2004). Carballa (2004) found that wastewater treatment facilities were only 60% to 90% efficient in removing tested (carbamazepine, diazepam, diclofenac, ibuprofen, naproxen, roxithromycin, sulfamethoxazole andiopromide) PPCPs. Additionally, the chemicals were adsorbing to solids and some were discharged as effluent into the aquatic environment (Ternes 1998; Hirsch 1999).

DNT contamination in ground water and other sources has long been an issue (Monteil-Rivera, F., et al., 2004). Contamination has come from wastewater discharge, burial, and the use of DNT that has leached through the soil and into the groundwater and other water sources (Darko-Kagya, et al., 2010). Although, contamination from DNT in

end-use public water systems in the United States has been limited, there is evidence of contamination in source supplies, potential for future drinking water contamination is possible (EPA, 2016). Testing for contamination of groundwater and water sources surrounding many Army ammunition plants have shown contamination from DNT (Thomas, 2007). Studies completed by the US Army Corps of Engineers found that contamination from explosive residues such as DNT led to waterfowl population reduction in Eagle River Flats, Alaska (Racine, et al., 1992). They also found concentrations near rivers adjacent to former ammunition plants ranged from 0.1-7.6 μg/L, and concentration found in Joliet Army Munition Plant potable water was found to be as high as 10,000 μg/L (EPA, 2016). As the use of DNT to manufacture products is continued so must the testing of water sources to prevent further contamination.

Additionally, as dyes continue to be used in the textile industry where large consumption of water is necessary and a similarly large volume of wastewater is produced, so exists a potential to contaminate water sources (Tan, et al., 2007). The National Toxicology Program found that benzidine based dyes had the potential to be "known human carcinogens". The use of dyes such as benzidine is greatly important due to the current effluent discharge of up to 200,000 tons of multiple types of dyes every year (House of Parliament, 2014). Many benzidine based dyes for example, were found in pigments from products to include printing inks, paints, plastics, and textiles (EPA, 2010). Although, various novel treatment methods have been used to remediate with some failures and some success, the most prevalent to date is adsorption using carbon media, furthering the need to enhance adsorption of carbon.

Treatment Methods

Research has shown effective DNT treatment options, including adsorption, chlorination, ozonation and advanced oxidation processes (AOP) using ultraviolet radiation (EPA, 2008). Limited research on individual CECs has given very little data on the overall removal of these contaminants (Starling, et al., 2018). Therefore, the adsorption, dilution, biodegradation, volatilization and oxidation of most CECs are unknown. Methods used most commonly for wastewater or discharge water is adsorption using GAC, which is either reactivated or incinerated after full saturation (Chen, et al., 2011).

Current wastewater treatment facilities rely on aerobic and anaerobic biological treatment, such as, activated sludge, anaerobic pond with facultative ponds, polishing ponds, trickling filters, and aerated ponds due to their lower operations cost (Zhou et al., 2016). Due to some of the current contaminants, wastewater facilities have added different technologies to their already existing infrastructure, such as, advanced oxidation, ultraviolet radiation, membrane technologies, chlorination, and adsorption technologies such as GACs (Salgot, et al., 2018). With the growing water requirement of the future, wastewater will continue to be reused even more than it is now. Most common reuse of wastewater is agricultural irrigation, aquifer recharge (urban, recreational and environmental uses), industrial cooling, or a combination of these (Huertas, et al., 2006). Although some contaminants are partially removed, a significant number of PPCPs remain in the water (Gogoi, et al., 2018). Presence of contaminants post water treatment furthers the need to improve water filtration systems.

AOP works by creating oxidation reaction between the oxidative radicals created by the AOP and the organic or inorganic compounds. AOP technologies have been found

to generally create hydroxyl radicals, that break down contaminants, reducing the secondary waste stream (Dewil, et al., 2017). A study completed by Serpone (2017), found that using AOP caused the degradation of some PPCPs, such as, non-steroidal anti-inflammatory drugs, antibiotics, and hormones. The EPA (1998) has also performed studies to show AOP reduces multiple dyes and DNT in bench scale tests up to 90%. By combining AOP with existing treatment processes, either before or after, can enhance the ability to reduce the overall concentration of contaminants (Comninellis, 2008; Van, 2015). Furthermore, project reports from Lakehurst, New Jersey and Bangor Naval Submarine Base, showed overall reduction in total organic carbon and explosive residue using AOP treatment by reducing both to 100 parts per million (ppm) and 2.9 parts per billion (ppb) respectively (EPA, 1993).

Reverse osmosis (RO), though effective, can greatly increase the cost due to the amount of equipment needed to be installed and maintained (De Gisi, et al., 2016). As one of the most sophisticated membrane liquid separation technologies, it is also one of the most costly to operate (Tang, et al., 2016). RO is the process of removing ions, molecules and particles from drinking water. RO treatment is accomplished by pumping contaminated water at high pressures through a semipermeable membrane to create potable water. One of the largest concerns is the waste product produced by rejected water with impurities. Discharged wastewater is usually high in sodium content, therefore, has little use and is disposed of. In order to improve the life of RO systems, they are installed as secondary treatment systems to existing aerobic or anaerobic treatments; thereby, reducing the amount of contaminants being filtered by the system initially. Studies have found that using RO treatment in conjunction with tradition wastewater treatment process increased

overall removal efficiency of TOCs in swine wastewater, although, effluent was still contaminated with antibiotic genes (Lan, et al., 2019). Lan's study found that RO removed only 78% of antibiotics studied, consequently, requiring another means of filtration.

GAC is used to adsorb multiple contaminants due to its attributable highly porous surface area (Zhang, 2018). The large surface area, microporous structure, and increased surface reactivity of GAC make it a good candidate as an adsorption media. GAC systems can vary in application depending on the multiple pollutants in the water being treated and the placement of the filtration system itself. GAC systems can be placed within an existing treatment system, reducing contaminants in influent water sources (SERDP, 2017). The placement of a GAC system can be used as either a primary or a secondary treatment system or in combination with traditional aerobic or anaerobic treatment systems. The primary utilization of GAC systems is in pump-and-treat methods used for the remediation of highly contaminated water sources. The secondary placement is standard when the TOC in water sources are high in order to reduce spent GAC, which contribute to higher maintenance, disposal or regeneration cost of GAC. In these cases, a primary step may be used to reduce TOC initially before water enters the GAC filtration process. Overall, GAC has shown to remove various pollutants from underground water and other water sources.

Adsorption capability of GAC varies due to the physical and chemical properties of the carbon and many variables to include the carbons' raw origin and method of activation. Activation changes to the carbon can vary due to the oxygen, hydrogen, sulfur and nitrogen present in the GAC functional groups, which bond within the structure attracting chemicals to adsorb or break down (Ilomuanya, et al., 2017). Small pore sizes rapidly adsorb contaminants, which may cause a negative side effect on water treatment

equipment due to increased saturation and overpressure within the system. The quick saturation can decrease overall performance by clogging from both over saturation and packing due to small particle sizes (EPA, 2014). Chemical adsorption happens from the chemical bond that the GAC may have from surface oxygen groups or the polarization of the carbon (EPA, 2014; Ilomuanya, 2017; Bhatnagar, 2013). Surface properties can vary from positive, negative, or neutral charges that the GAC may have. The oxygenated GAC is key in creating the hydroxyl radical required for adsorption of the contaminants. Therefore, depending on the charge characteristics of the contaminant being removed, the selection of GAC surface properties are important.

Relevant Research

Physical/Thermal Activation of Carbon

The most common process of activating carbon is steam or physical activation. The activation of carbon can give carbon specific adsorption characteristics that remove certain contaminants (Fitzer, et al., 1971). Physical and chemical interaction of the GAC and contaminants occur through the physical attraction of the porous surface as well as the chemical attraction through polarity of the surface of the GAC (Fitzer, et al., 1971). There are two stages commonly used to activate carbon. The first stage consists of introducing heat to the raw material with inert gas in an oven, creating the carbon through carbonization. Carbonization is the process of using heat to remove moisture and non-carbon species (Zhi, et al., 2015). In order to reduce waste, temperatures are set below 700°C, reducing the ash throughout the process. The second stage, steam activation, takes

place at temperatures between 700°C and 1000°C, in steam and CO_2, and lower temperature in air (Karanfil, et al., 2000).

The usual commercial choices of inert gas are same as previous, steam, CO_2, air, or their mixtures. Steam activation increases pore structure as a result, increasing the overall surface area of the carbon. Chemical carbon activation occurs by removing small carbon particles from the larger, stronger carbon. Washing the activated carbon (AC) occurs after a set time per individual manufacturer specification, to remove any unwanted contaminants and to adjust the pH levels to manufacturer specifications. The last step for the AC is for it to be dried (removing residual solution from washing) and stored for future use.

Chemical Activation of Carbon

Chemical activation is one of the least common commercial methods. In this process, the raw materials are mixed with a solution of dehydrating agent such as zinc chloride ($ZnCl_2$), phosphoric acid (H_3PO_4), sulfuric acid (H_2SO_4), or potassium hydroxide (KOH) (Pollard, et al., 1992; Zor, et al., 1998). The mixed solution hinders or eliminates the formation of tars and unwanted contaminants during the carbonization process. The carbonization processes are accomplished at much lower temperatures than steam activation and range from 400°C to 800°C (Ali, et al., 2012; De Gisi, et al., 2016). The acidic solution also minimizes the amount of shrinking during carbonization, allowing a larger porous and surface area, creating a better adsorption capacity. Chemical activation has key advantages over physical activation, which includes lower temperatures, single step, higher product yields, higher surface areas, and better microporosity distribution control (Ali, et al., 2012; Gisi, et al., 2016). The advantages

are due to the phosphate or dehydrating agent residual in the carbon during the chemical activation. The oxidation of the carbon creates the radicals needed to attract or break down contaminants during use (Menya, et al., 2018).

Surface Modification

Acid treatment is one of the most common methods of surface modification to achieve a desired adsorption property to target a certain contaminant or overall increased adsorption capability of GAC. The acid treatment is used to oxidize the carbon surface, thus, increasing the oxygen functional groups which break down or adsorb contaminants (EPA, 2014; Ilomuanya, et al., 2017; Mcquillan, et al., 2018). The acid solution concentration, time mixed, and the temperature during mixing all affect the modification of the carbon. Therefore, the procedures and methods used to modify the carbon need to be carefully selected to create the desired effects. The acid solution used can determine the pore size and surface area after acid treatment. In general, overall hydrophilicity of the carbon is increased, which leads to an increase in contact time and area of the carbon and contaminated solution being treated (Mcquillan, et al., 2018).

Base treatment of carbons is accomplished using high temperature similar to the physical/thermal process. Treatment is prepared using an inert gas or removed oxygen furnace, acid solution and generally some form of impregnation that will increase nitrogen functional groups (Bazula, et al., 2007; Mcquillan, et al., 2017). The base treatment creates a positive charge in the carbon that attract acidic contaminants (Ilomuanya, et al., 2017; Mcquillan, et al., 2017). Some concerns are the possible decrease in the surface area to include the pore size within the carbon. Therefore, the inert gas chosen needs to be verified to create the pores sizes desired (Jansen, et al., 1995; Mcquillan, et al., 2017). Choosing

the optimal inert gas can determine whether the pore size and surface area is complimentary to the contaminant. The overall temperature range is also a consideration as to not deteriorate or decrease surface area and reduce waste.

Electrochemical Modification

The most general electrochemical process consists of a cell with three main components: a fuel or auxiliary (anode) electrode which provides the power source entry, a working or oxidant (cathode) electrode, and the material being modified that is normally in an electrolyte solution (Fan, et al., 2018). Electrolyte solutions can be made of multiple types of solution, including phosphoric, sulfuric, and nitric acid. A common problem with the modification process is the poor conductivity of carbon due to the low oxygen containing surface functional group. For that reason, the need to introduce an electrolyte to assist in the electrochemical treatment is necessary. An electrolyte, such as nitric acid is used to activate carbon in the chemical activation process, making it a good choice for an electrolyte solution in an electrochemical treatment (Wang, et al., 2000).

Recent research has shown carbon has the ability to be modified using electrochemical modification to improve ionic exchange (Garcia, et al., 2018). Research has shown that the increase of oxygen in water and GAC also increases the adsorptive capacity of GAC. Therefore, total adsorption capacity of GAC can be changed using redox principles. Electrochemical modification occurs by increasing the surface oxygenated groups, divided in three main groups: chemically bonded groups (carbonyl), surface groups (carboxylic) and redox functional groups (quinine). Electrochemical modification of carbon is most commonly used to enhance the electric conductivity of carbon for use in electrical conductors and battery technology (Wang, et al., 2013; Fan, et al., 2018). The

activation of carbon treated with nitric acid (HNO_3) has shown to increase oxygen containing surface functional groups (Li, et al., 2009; Wang, et al., 2013). Further studies found that the pretreatment of HNO_3 had little to no change in nitrogen associated functional groups in chemical modification (Zanella, et al., 2014). However, due to current cost of electrochemical modification, no advancement in either activating or further modifying activated carbon using electrochemical modification has occurred.

As the consumption of carbon in water treatment increases, the financial burden of creating carbon and disposing spent carbon also increases (Berenguer, et al., 2010). Reactivating GACs reduces the amount of waste buildup and contributes to cost avoidance of not having to produce new GAC (Dingshan, 2010; Guangyu, 2006). The process of regeneration consists of desorption of the contaminants with minimal modification to the carbon materials. Some concerns of current methods of regeneration are the cost due to large energy consumption and physical carbon loss using thermal regeneration (Alvarez, et al., 2004). This is due to the cost of transporting spent carbon as well as the cost of energy to regenerate the spent carbon. A growing research area is the regeneration of GAC through the electrochemical treatment process (McQuillan, et al., 2018). Utilizing electrochemical modification has shown regeneration is possible and showed GAC to reach up to 95% of original adsorption capacity (Zhang, H., 2002).

Using what was learned from electrochemical regeneration and the electrical enhancement of carbons through the electrochemical process, the further enhancement of adsorption through electrochemical modification will be discussed. Using the electrode principles of cathodic and anodic regeneration, the redox of GAC is possible. Cathodic regeneration is the reducing of ions, which is most commonly used to enhance electronic

capacity. Although cathodic regeneration does increase surface oxygen, the fouling of the reducing electrode has been a concern at normal operating conditions (Fan, et al., 2018). Anodic regeneration is the oxidizing or increasing of ions throughout the carbon. Berenguer's (2010) research showed by using anodic treatment the oxidation of carbon yielded a comparable surface oxidation of carbon oxidized chemically.

Electrochemical modification can be accomplished by reversing the objective of modification for electronic use and using the enhancement of adsorption as the goal to improve the oxidation of carbon. Electrochemical modification is accomplished using an auxiliary electrode as the anodic electrode to allow the carbon oxidation to occur near and throughout any contact with the electrolyte solution. Using a nitric acid solution, a known chemical activating agent allows the current to pass through the complete slurry of carbon during modification in order to ensure complete electrochemical modification. The modification predominately provides a larger surface area and increases functional groups, enhancing the adsorption capability of GAC. The treatment achieves the enhancement of adsorption by allowing more oxygen within the pores and surface area of the GAC (Narbaitz, & Cen, 1994). The added oxygen functional groups increase the attraction of contaminant electrons in an attempt to enhance adsorption (Gokce, 2014). The benefit of further modifying commercially acquired GACs is potential reduction in disposal costs and reactivation costs. Electrochemical modifications of GAC will ultimately provide the potential to complete electro-oxidation of the carbon, and so, increasing the amount of bonded functional groups (Alegre, et al., 2018). As the advancement of electrochemically modified carbon for energy uses increase so must the progress of electrochemical modification of carbons used in adsorption processes.

Summary

In summary, this chapter focused primarily on contaminants such as CECs and DNT, the past, present, and significant treatment methods used to remove contaminants, as well as relevant research pertaining to the electrochemical modification of GAC.

Chapter 3 will focus on the methodology, to include the process taken to set up experiments, gather data, and the methods used to analyze the data. Methodology provides the process to measure the concentrations of DNT, BB and MB dye solutions during treatment with as is and modified GACs over established time intervals. It will also go in depth on the analyzing of sample concentrations at the set intervals to allow the calculation of adsorption capability of GAC when comparing the as is and modified GAC species.

III. Methodology

Chapter Overview

This chapter describes the methods and process used to sieve, decant, dry, electrochemically modify, test, and analyze the adsorption of carbon to support the researcher's questions. The first test used crushed and sieved GAC in multiple bottle bench tests to investigate whether electrochemical modification of carbon increases the adsorption capacity of various carbon species. The second test was used to characterize a specific coconut shell based GAC to determine the effect of time on the adsorption capability of the carbon. Each method will be described in a separate section, including information about the materials used, the process methodology, material preparation, and data analysis.

Materials

Deionized Water

The deionized water used for the experiments came from the Air Force Institute of Technology laboratory reverse osmosis system. Deionized water was used to remove any probability of contaminants or noise in analysis from using standard tap water.

Brilliant Blue (BB) Dye

The BB ($C_{37}H_{36}N_2O_9S_32Na$) was made by Sigma-Aldrich with a greater than or equal to 97.0 % purity and a molecular weight of 792.86 g/mol. The dye was used for multiple carbon adsorption experiments. The first few experiments were for proof of concept using the bench bottle testing (test using known level of contaminated solution with carbon to determine the amount of adsorption) method to determine amounts of

carbon to use in future experiments. The final solution concentration for analysis of contaminant removal over time was 5 ppm. Past research has shown BB dye to be an anionic dye; therefore, BB dye was used to determine anionic capabilities of the carbons. Figure 1 depicts the initial stock solution of BB dye with the 500 mL bottle and pipette used to mix the batch bottles used in the experiments.

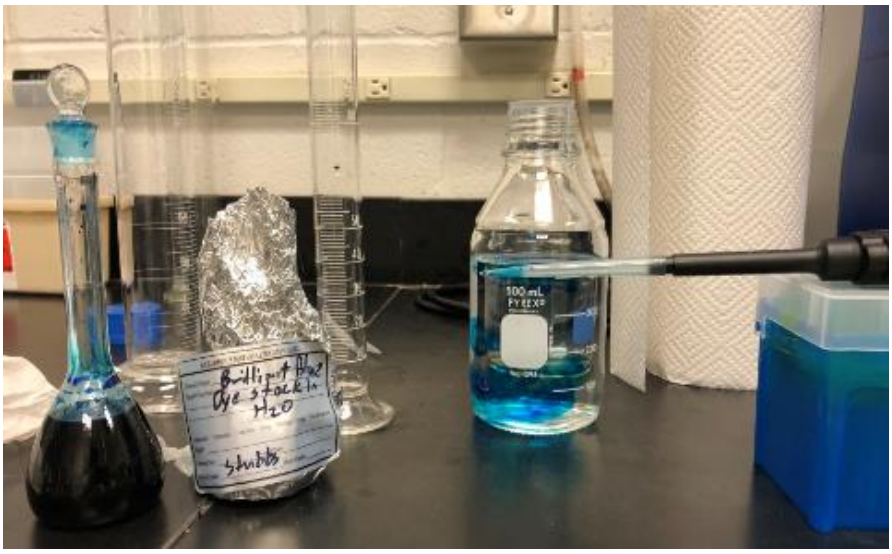

Figure 1. The Brilliant Blue dye (BB) dye shown mixed during pilot study to determine the amount of GAC to be used in future experiments.

Methylene Blue (MB) Dye

The MB ($C_{16}H_{18}ClN_3S * 3H_2O$) dye was from Sigma-Aldrich with a greater than or equal to 82.0% purity and molecular weight of 373.89 g/mol. The dye was used in the final analysis of cationic and anionic capabilities of the various carbon candidates, both as is and modified. Past research showed MB dye to be cationic; therefore, it was used to determine cationic adsorption capabilities of the carbons.

Toluene

The Sigma-Aldrich toluene (CH_3) was 99.89% purity and had a molecular weight of 92 g/mol. Toluene has a high volatility, making it easily released into the air. During experiments, there was a variety of analysis difficulties due to its volatility, which led to the removal of using it for these experiments. Figure 2 shows the toluene being mixed to 10 ppm to be used in the experiments to determine the adsorption capability of GAC. The solution was made at a higher concentration to allow it to be used in diluted bottles for multiple experiments.

Figure 2. The Toluene and DNT solutions being prepared and mixed by stir bar and a stir plate.

2,4-Dinitrotoluene

Sigma-Aldrich 2,4-Dinitrotoluene (DNT) was used as a contaminant to test the adsorption capacity of the GACs and carbon nanofibers (CNF) used in the experiments. The DNT used was a greater than or equal to 97.0% purity with a molecular weight of 182.13 g/mol. A high concentration solution was used to

create multiple consistent 10 ppm DNT solutions in 500 mL amber bottles. Figure 2 shows the 1000 ml volumetric flask, deionized water, and the DNT used to make the starting 100 ppm concentration that was diluted for use in the multiple experiments.

Calgon Filtrasorb® 600 GAC

Filtrasorb® 600 GAC is frequently referred to as F600 and is one of the most commonly used GACs for water remediation from various contaminants. The GAC is made of bituminous coal. Due to its acid wash, F600 has a high surface area, pore volume, density and optimized pore structure (Calgon, 2018). The density (0.62 g/cc) of this GAC is listed as one of its benefits when activated, in addition to creating low and high energy pores due to ion interface. Moreover, F600 can be recycled and reused by thermal reactivation, hence, reducing the cost of replacing the spent GAC after saturation. The limitation of F600 is the amount of and cost of bituminous coal used to make and regenerate the GAC as well as the cost of the process.

Evoqua AquaCarb® AC1230CX GAC

Traditionally, coconut based activated carbons were used for water with low VOCs and not water with high total organic compounds. This coconut shell carbon is activated in a manner to produce high micropore structure, creating a fast kinetic adsorption. Although it has a lower density (0.43-0.46 g/cc) than most GACs, it is advertised to also adsorb larger molecular weight compounds (Evoqua, 2017). Evoqua 1230CX can also be regenerated to near virgin GAC adsorption capacity. Limitations of this GAC include the added cost of modifying coconut shell carbon to match the quality of bituminous carbon and the regeneration cost.

Figure 3. Evoqua AquaCarb® AC1240AW, AC1230CX GAC and CABOT NORIT GAC 400 samples used as is and electrochemically modified to determine any adsorption enhancement from modification.

Evoqua AquaCarb® AC1240AW GAC

AC1240AW GAC is an anthracite coal based carbon that is activated by high temperature steam activation. The GAC is acid washed after activation to reduce ash content and create chemical stability. This produces an advertised unique pore size distribution, low density, and high adsorption capacity with a low apparent density of 0.36-.40 g/cc (Evoqua, 2017). The pore size is of microporous structure; therefore, faster kinetic adsorption and longer bed life is expected. This GAC can also be regenerated to near virgin GAC adsorption capabilities. Limitations of Evoqua 1240AW GAC are the initial cost of the anthracite coal to produce the GAC, the added cost of chemical activation, regeneration, and the cost of loss in material during the regeneration process.

CABOT NORIT GAC 400

NORIT GAC 400 is produced from bituminous coal by steam activation. The activation produces a GAC with an apparent density of 0.49 g/cc. CABOT advertises this carbon candidate as having excellent adsorption properties for removal of odor, taste and color in water and industrial process application (CABOT, 2018). Regeneration of GAC 400 can be accomplished to recover 97% or greater of the original adsorption capacity. Figure 3 shows the original container that the as is NORIT GAC 400 comes in. Limitations of this GAC are the cost of purchasing the virgin GAC, regeneration cost, and cost in loss of material in the regeneration process.

Applied Sciences Inc. PR-25-XT-PS CNF

The carbon nanofiber that was used (PR-25-XT-PS) is a pyrolytically stripped carbon nanofiber with an average diameter of roughly 100 nanometers and a low chemical vapor deposited layer of carbon over the surface of the hollow fiber. Due to its nano-sized structure, it has a density of 0.16 g/cc (Pyrograf ®, 2019). Figure 4 shows the sample donated by Applied Sciences, Inc in its original packaging prior to electrochemical modification.

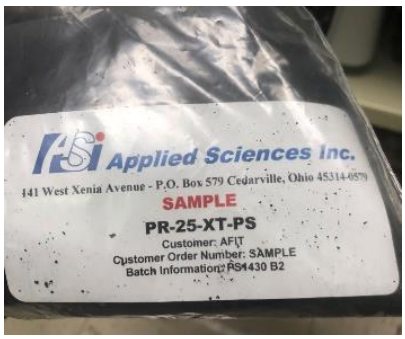

Figure 4. The Applied Sciences Inc. PR-25-XT-PS CNF was used as an innovative material to determine adsorption capabilities.

Nitric Acid

Fisher Scientific nitric acid (HNO_3), optima grade, was used to create an acid bath and used as an electrolyte during the electrochemical modification process. The acid solution is mixed with carbon to chemically etch the carbon and serve as an electric conductor medium throughout the carbon. Figure 5 shows the source of nitric acid, its manufacturer bottle, and the volumetric flask used to mix the solution using hand shaking, a small stir bar and stir place.

Figure 5. The Optima Grade Nitric Acid being mixed to create the electrolyte solution used in the electrochemical modification of the carbon materials.

Sieves, mortar, and pestle

A sieving process allows the consistency of carbon particle sizes to be characterized to those of the desired sieve size. Figure 6 depicts the sieve stacked in the manner it was used, 80 sieve size, 120 sieve size and the 200 sieve size used to catch the final wanted sized carbon. Also pictured is the mortar and pestle used to crush the virgin GAC species prior to the sieving to proper size.

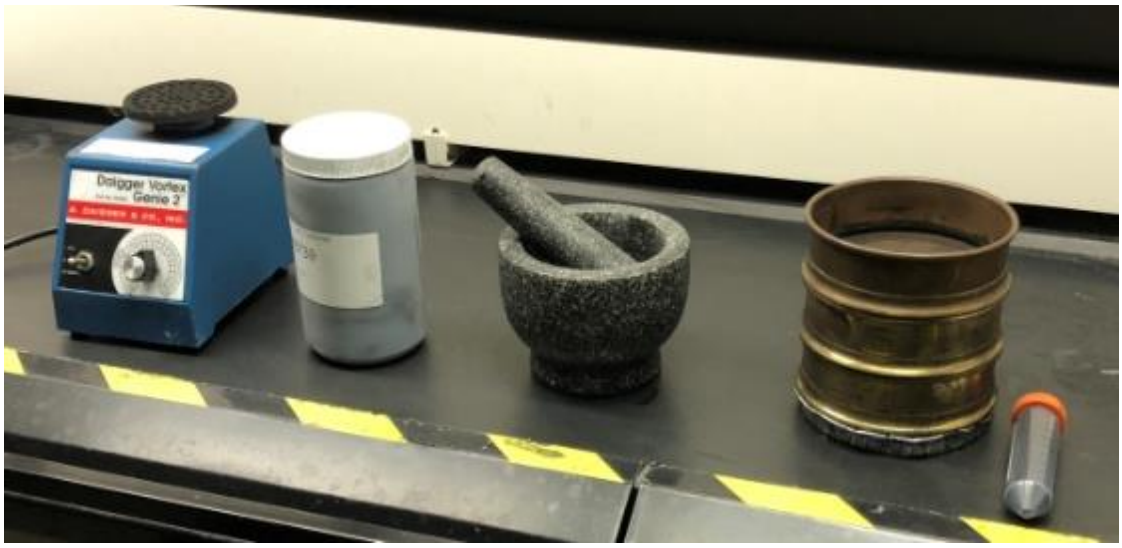

Figure 6. The tools (mortar, pestle, sieves, and shaker) used to crush and sieve.

Electrochemical Cell

An electrochemical cell (Dr. Bob's Electrochemical Cell Kit, 990-00193, Warminster, PA) was used to modify the carbon in hopes to enhance the adsorption capacity of the carbon. The cell uses a reference electrode (Gamry Silver/Silver Chloride Reference Electrode (Ag/AgCl) 1004G), platinum electrode as a working electrode, and auxiliary electrode where the charge begins. Figure 7 depicts the cell used in the experiment with the electrodes shown (the auxiliary connected to the green wire, the working electrode connected to the red wire and the reference electrode on the black wire).

Figure 7. The electrochemical cell used in the modification of virgin GAC and CNF.

Electrochemical Potentiostat System and Electrochemistry PowerSuite ™ Software

Electrochemical potentiostat system (PARSTAT® 2273, Princeton Applied Research, Oak Ridge, TN) was used to control the current through the sample of acid solution and carbon mix. It allows the amount of current and length of time to be present, giving the user the ability to analyze the data in real time to determine if changes need to be made to the procedure. The equivalence or stabilization of potential energy is gathered from the graph in real time as shown in Figure 8, where the positive and negative current is seen stabilizing throughout the process on the Electrochemistry PowerSuite ™ software. The software provides the needed parameter controls to set the current amperage, time, and to monitor the treatment graphically as it is occurring.

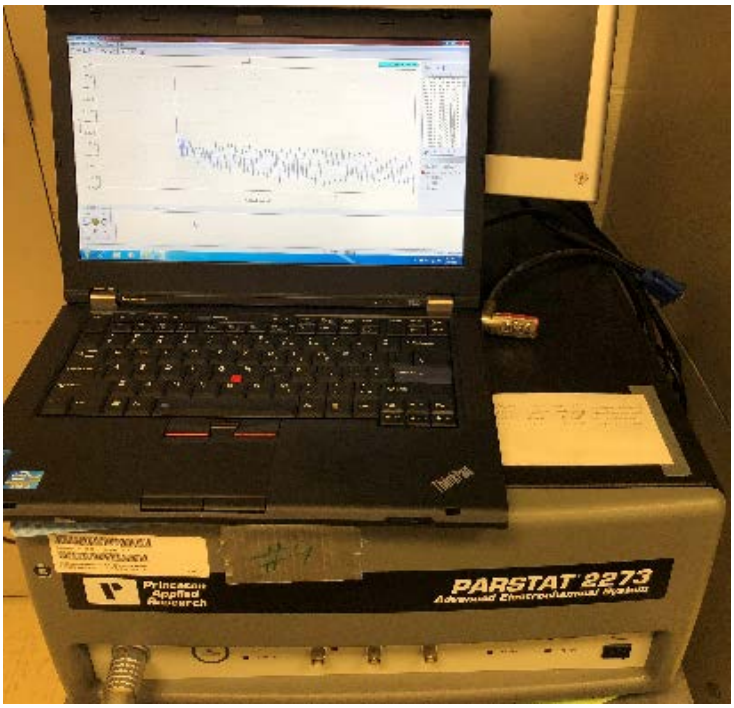

Figure 8. The electrochemical potentiostat system was used in the controlling and monitoring of the electrochemical process.

Centrifuge

Contaminant solutions were centrifuged (Model # 5810 R; Eppendorf, Hauppauge, NY) at 4000 rpm for 10 minutes at 6 degrees Celsius, causing the carbon to settle at the bottom of the vials. The process removes possibilities of errors due to refraction of light off carbon or absorbance of light by carbon in the UV-Vis. Figure 9 shows the centrifuge used with two samples to cause the carbon to settle at the bottom of the vials in order to help remove errors when using the UV-Vis.

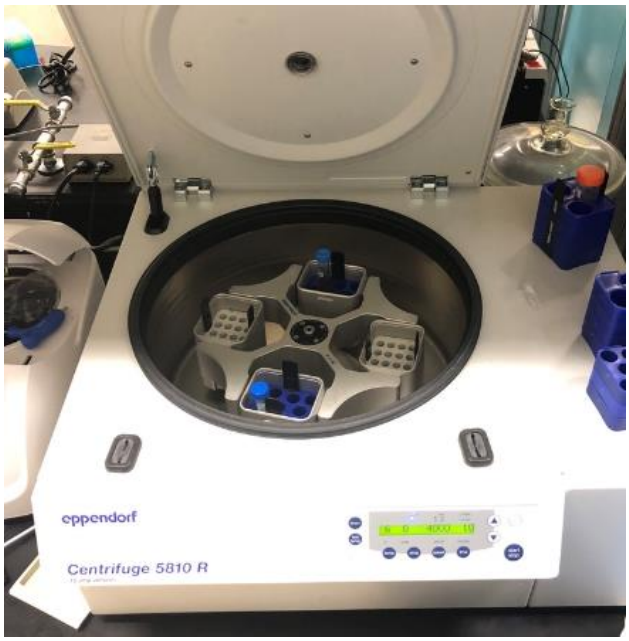

Figure 9. The centrifuge was used to remove GAC from the DNT, BB, and MB dye solutions in the 15 mL vials to be analyzed through UV-Vis.

Ultra Violet Visual Spectrometer (UV-Vis)

UV-Vis (Agilent Technologies, Cary 60 UV-Vis, Santa Clara, CA.**)** was used to determine the concentration of the contaminants (BB and MB dye and DNT) that were used in the bench bottle tests throughout the experiments. It uses the amount of absorbed light given at an initial wavelength of light passing through the spectrophotometer. The absorbance of light, A, is give from the Equation 1 (Beers-Lambert Law), where I_0 is the intensity of the initial light wavelength, and I is the measurement of the light intensity wavelength after passing through the sample. The UV-Vis used had a 190-1100 nm wavelength range, with a ± 0.5 at 541.94 nm wavelength giving it a high accuracy (Agilent Technologies, 2011).

$$\boldsymbol{A = log_{10} \frac{I_0}{I}} \qquad \text{Equation 1}$$

Figure 10 shows the Cary 60 UV-Vis used in the experiments with the sampled solutions seen next to it ready to be analyzed, with the laptop showing the concentration of contaminant on the screen

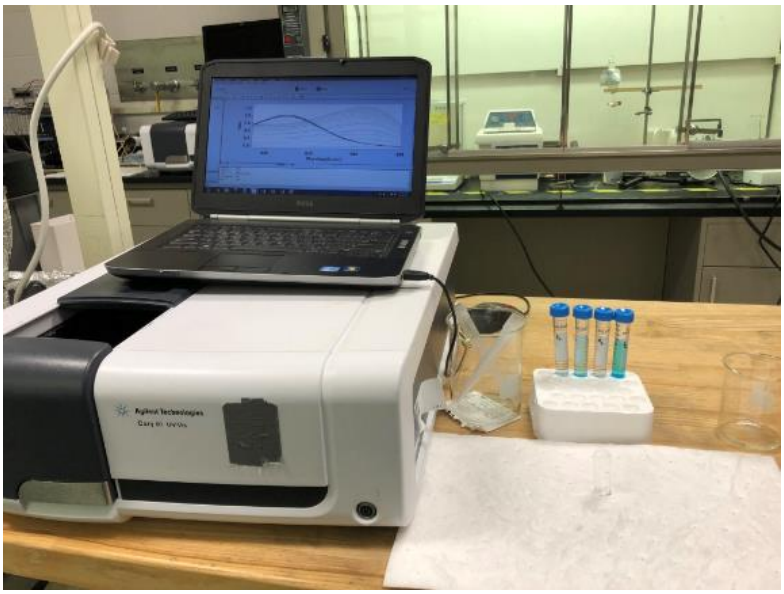

Figure 10. The Ultra Violet Visual spectrometer (UV-Vis), used to analyze remaining concentration of DNT, BB, and MB dyes.

Cuvettes

Cuvettes used were made of quartz to minimize staining from dyes and to allow the UV light wavelengths to pass through the material. The optimal wavelength ranges for quartz is from 190-2000 nm. The cuvettes used in this research had a 4 mL capacity, but for this experiment they were only filled with 3.5 mL of solution to be analyzed. During testing, cuvettes were wiped with low lint towels to remove any water stains, smudges or solution from the outside walls of the cuvettes. Figure 10 shows the cuvette used for the experiment on the center of the white towel, rinsed and wiped, ready for next sample.

Methods

Carbon Preparation

Carbon was sieved after crushing the carbon using a mortar and pestle. The crushing gave the ability to assure the most even size throughout all the carbon species, especially after sieving. The sieving process allowed crushed carbon to pass through an 80 sieve size, a 120 sieve size, and retain what accumulated at the top of the 200 sieve size. Any finer material that passed the 200 sieve size was caught on a pan at the bottom of the sieve stack and discarded. Figure 6 depicts the mortar and pestle used to crush the carbon as well as the sieve pans stacked in the manner they were used.

Decanting

The decanting process is the rinsing of the crushed carbon to remove any fine particles and contaminants that may be trapped in the carbon. The crushed and sieved carbon specimens were placed in 250 mL beakers where they were rinsed with deionized water and allowed to settle for some time (30-45 min). As the carbon settled, particles that floated to the top were disposed of and the rinsing was repeated until the deionized water was clear of any floating particles. Caution was taken with the Evoqua brand GACs as they were less dense than the other GACs, and so, taking longer to settle. The CNF used did not have the density to be decanted, so it was only washed and dried in the oven. After the carbon species were rinsed and decanted, they were placed in an oven to dry at 350 degrees for 12 hrs. Figure 11 shows the GACs being rinsed and decanted prior to being dried in the oven.

Figure 11. GAC being washed and decanted using deionized water and 250 mL beakers.

Dye Solution

Each bottle of dye solution used in the experiments was prepared using the following steps to keep consistency throughout each experiment. All 500 mL amber bottles were washed and rinsed using deionized water and dried prior to use. Each amber bottle was filled with 433 mL of deionized water using a 500 mL and 50 mL graduated cylinder. Using BB dye solution that was previously mixed, 547 μL of the solution was pulled using a 1000 μL pipette and mixed with the deionized water in the 500 mL amber bottle. The first mixing was completed by hand shaking, followed by mechanical mixing with a stir bar and stir plate. Similarly using MB dye solution, 1.019 mL of the solution was pulled using a 1000 μL and 1-50 μL pipette and mixed with the deionized water first by hand shaking, then using a stir bar and stir plate. Figure 1 shows the initial process used to create the dye solutions for both BB and MB dyes as previously described. Figure 12 depicts the 500 mL amber bottles filled with dye solution and numbered for the multiple experiments, waiting on the carbon species to be added while continuing to be stirred.

Figure 12. Solutions containing 5 ppm BB and MB dye solution being stirred prior to adding carbon for the experiments.

DNT Solution

A high concentration DNT stock solution was prepared by mixing 103 mg of DNT in a 1000 mL volumetric flask with 1000 mL of deionized water to create a 100 ppm DNT solution. The 500 ml DNT solution bottles used in individual experiments were then prepared by diluting the 100 ppm DNT solution. The 100 ppm stock solution was used to prepare 10 ppm DNT solutions in the 500 mL amber bottles. The 500 mL amber bottles were washed and rinsed using deionized water and dried prior to use. The amber bottles were filled with 433 mL of deionized water using a 500 mL and 50 mL graduated cylinder. Using the DNT high concentration solution (100 ppm DNT solution), 43.3 mL of the solution was pulled using a 25 mL glass pipette and poured in the amber bottles. Mixing was completed by hand shaking, then using a stir bar and stir plate as shown in Figure 2.

DNT, BB and MB dye UV-Vis Calibration

A calibration curve was generated to achieve confidence in the precision and accuracy of the solution measurements. The solutions were made by diluting the high concentration stock solution with deionized water to create a 10 ppm starting concentration. The calibration curve was developed from five known solutions. The solution was diluted to known values of absorbance at 10 ppm or 100% then 50%, 25%, 10% and the blank level with deionized water. The absorbance is given by the UV-Vis at each known ppm concentration giving the appropriate and modified bottle test solution sampled at the time intervals and analyzed using the UV-Vis.

Electrochemical Modification

An electrochemical modification treatment was used to create the oxidation on the carbon surface for all the specimens. The carbon samples consisted of Calgon Filtrasorb ® 600 (F600) a bituminous coal, Evoqua AquaCarb® 1230CXPB55 a coconut shell carbon, Evoqua UltraCarb® 1240AW an anthracite coal carbon, NORIT GAC 400 a bituminous coal, and Applied Sciences, Inc. PR-25-XT-PS carbon nanofibers. The first step was to create a nitric acid solution to saturate the carbon and perform as an electrolyte for the current to flow throughout. A pipette was used to pull 1.6 mL of nitric acid to be mixed with 20 mL of deionized water to make the nitric acid solution used as the electrolyte solution. The solution was stirred using a stir plate for 30 minutes to ensure a complete mixture throughout. A 1 g sample of carbon was weighed using a microbalance for all carbon specimens. The samples of carbon were rinsed and decanted prior to use to remove small particles and any possible contaminations which was accomplished after the sieving

process. The 1 g of carbon sample was placed in the cell and mixed with the acid wash solution using a stir plate. Figure 13 closely depicts the carbon in the electrolyte solution made from the nitric acid, as well as the electrodes used to electrochemically modify the carbon.

Figure 13. Electrochemical cell showing hydrogen bubbles being released at the platinum electrode, creating the strong oxidants such as hydroxyl radicals.

In order to achieve proper saturation and mixture, the cell was placed on the stir plate, secured using tape, and allowed to continue to stir. The stir plate was set at 270 RPM for all samples to maintain consistency throughout all the experiments. This allowed for mixing of the carbon and nitric acid wash solution. The working, auxiliary, and reference electrodes were cleaned prior to submerging in the cell. Caution was taken when polishing the auxiliary electrode as too much polishing can remove and degrade the contact surface causing more resistance during the electric current transfer. The working

electrode was placed in the mixture roughly 3-5 mm from the top of the sample as it rests in the cell. The auxiliary electrode was placed on the surface of the sample in order to make certain that the current would pass through it. The sensing electrode was placed 3-5 mm near the top of the sample, similar to the working electrode. The gas tube, where the nitrogen gas flows through, was placed into the sample in order to mix and remove oxygen from the solution mixture. Looking closely at Figure 13, the placement of the electrodes can be seen in the solution for the modification process. As the solution and samples were being stirred, nitrogen was allowed to flow at 3-5 psi through the mixed solution. The nitrogen flowed for 30 minutes and was allowed to bubble in the mixture in order to remove oxygen from the cell. Figure 7 depicts the actual placement of the gas tube used for the nitrogen flow prior to the electrochemical process. The time for nitrogen flow was established using previous experiments from electrochemical modification for electronics purposes (Wang, et al., 2000). Once the mixture was saturated and nitrogen had flowed sufficiently, the mixture was allowed to settle to the bottom of the cell as shown in Figure 13.

The electrochemical modification process is initiated when the electrochemical potentiostat is used to begin the oxidation process. The process was set to run for a total of 300 seconds at 0.5 amp. Using the Electrochemistry PowerSuite ™ software, a real time analysis of the equilibrium of electric potential energy can be monitored, allowing for decision to change or continue the modification process as programmed. Figure 8 shows the potentiostat and the software being used to determine whether equilibrium is being reached. Although subtle, a closer look at the graph in Figure 14 shows that at near 250 to 300 seconds the variation of current change is limited; therefore, oxidation has

been completed in the given material and solution mixture. The stabilization is seen as the difference in the minimum and maximum wave pattern on the graph. It also shows the stabilization of the carbon species being modified, where the difference in the amperage change is minimal. As the difference in changes in the positive and negative charges become less, the confirmation of oxidation is reached. The oxidation, mostly occurs at the cathode and anode, though due to the electrolyte solution (nitric acid), the current can cross throughout the carbon and solution mixture, giving a more efficient oxidation process.

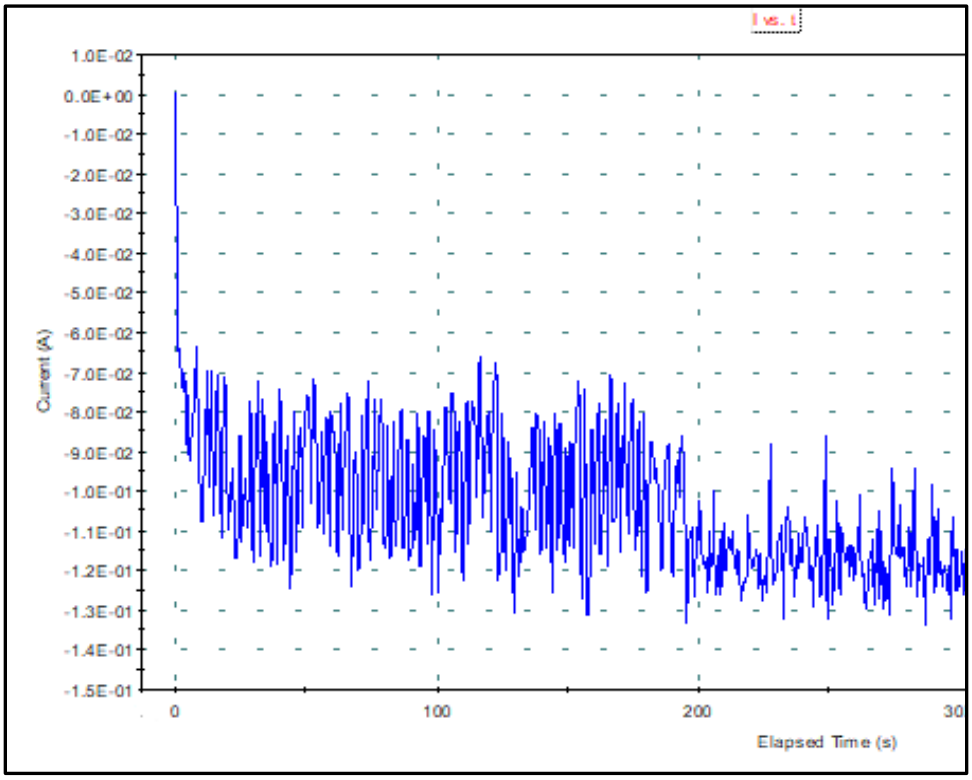

Figure 14. Electrochemical stabilization of the carbon and nitric acid solution used given a graph taken from the potentiostat system program (Electrochemistry PowerSuite ™ software).

Bench Bottle Tests

Bench bottle test methods were conducted to test, analyze, and compare the adsorption of the as is and electrochemically modified carbon species. The method utilized the 10 ppm DNT, 5 ppm BB and 5 ppm MB dye solutions in the 500 mL amber bottles. The carbons (Calgon Filtrasorb® 600, NORIT GAC 400, Evoqua AquaCarb® AC1230CX GAC, Evoqua AquaCarb® AC1240AW GAC, and Applied Sciences Inc. PR-25-XT-PS carbon nanofibers) were added to the solutions in 25 mg, 18 mg, 12.5 mg, and 6 mg across multiple experiments. All GAC samples used were those that had been sieved, decanted, and oven dried as previously described. Due to the small size and low density of the CNFs, they could not be sieved and decanted, though, a rinse and oven drying was performed to remove as many contaminants as possible.

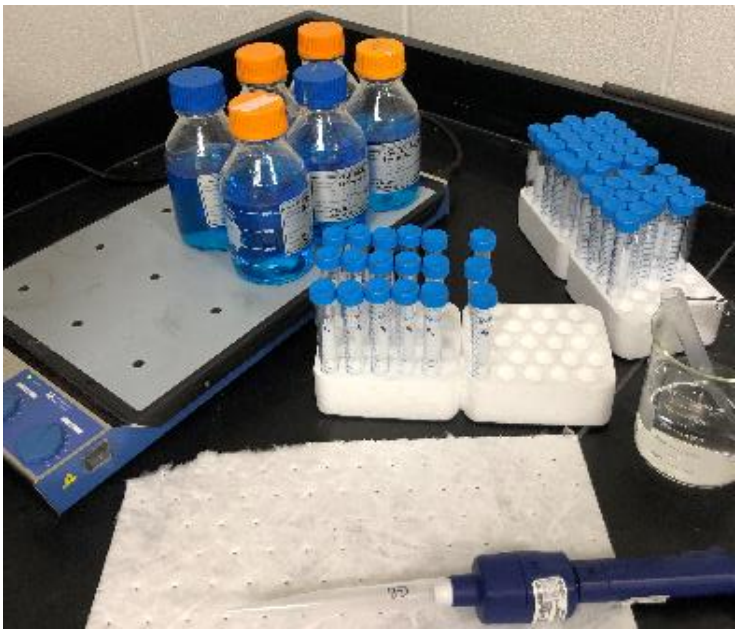

Figure 15. Bench bottle test used in the pilot study to determine the amount of carbon needed to remove the dye from the solution.

The kinetic sorption of the carbon experiments was conducted taking samples at pre-determined time intervals for all experiments. An initial concentration of the mixed 433 mL of deionized water and contaminant solution was taken to compare with those taken over time with carbon mixed into the solution to adsorb contaminants. Samples were taken using a 0-10 mL pipette to pull 10 mL solution from the amber bottles and then transferred to a 15 ml vial. The vials were then placed in the centrifuge to remove any carbon mixed in the solution and forced it to settle. This removed possible error given light refraction or absorption when using the UV-Vis to analyze samples. The 15 mL vials were then taken from the centrifuge and a 0-5 mL pipette was used to transfer 3.5 mL solution to the cuvette. The solution sampling occurred at times, 0, 10, 20, 40, 80, 160 minutes and at 24 and 48 hrs.

UV-Vis analysis

The UV-Vis analyses were performed with range system setting for each contaminant. Parameters were set which allowed the UV-Vis to only analyze at specific wavelength ranges characteristic of the contaminants used in each experiment as well as the time taken to complete the analysis. The time setting ranged from slow to fast, where slow setting are used for contaminants that are hard to be analyzed with UV and fast for the contaminants more easily seen with UV. Setting for the BB dye were set to fast analysis using a light wavelength range of 615-680 nm with BB absorption maximum at around 630 nm. The MB dye analysis was set to fast analysis with light wavelength range scans of 615-680 nm and the target concentration scan at roughly 665 nm. DNT was analyzed using the fast setting and a wavelength light range of 245-260 nm with maximum absorption at around 250 nm. Table 1 shows an example of the data given by the UV-Vis to determine

the concentration given 25 mg of NORIT 400 GAC in 10 ppm DNT solution at times 0 and 10 minutes. The highlighted numbers are of the highest concentration reading at each time sampled. For example, T_0 was the initial time without carbon and 10 ppm DNT concentration being equal to the highlighted number in the absorbance column, T_1 at 10 minutes and the highlighted number being the highest concentration reading at that time.

Table 1. UV-Vis data sample

25 mg of NORIT 400 with 10 PPM DNT solution					
N400 T_0		N400 T_1		N400 T_2	
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
252.9928	0.664528	252.9928	0.554339	252.9928	0.468321
252.0084	0.666318	252.0084	0.555414	252.0084	0.469383
250.9847	0.668118	250.9847	0.557403	250.9847	0.470825
250.0002	0.668576	250.0002	0.557952	250.0002	0.471636
249.0156	0.668524	249.0156	0.558407	249.0156	0.472418
247.9915	0.665147	247.9915	0.556292	247.9915	0.470578
247.0068	0.661494	247.0068	0.552225	247.0068	0.467382
245.9825	0.654955	245.9825	0.547066	245.9825	0.463062

Scanning Electron Microscope

A Scanning Electron Microscope (SEM) was used to create images of the carbon samples as is and modified. The SEM works by focusing electrons at a sample and taking the scanned beam of electron interaction with the sample to create an image. Care in loading the sample was taken in order to prevent contamination that would render errors in the SEM images. Samples need to be maintained dried in order to not have noise created by moisture contamination in the sample. Cleanliness in loading the samples on the SEM stubs is also crucial as any debris and smudges from previous samples can interfere with the electron scanning. Methanol was used to prep the studs prior to the adhesion of the

double sticky side carbon tape. Figure 16 shows the tools used in the loading of the studs and carbon. The stud on the right is shown with the carbon tape adhered to the stud and ready for the carbon species to be placed on it. The carbon species placement on the stud was completed by placing a small amount of the each as is and modified carbon specimen on separate tape and pressed down to assure adhesion. This is essential as the SEM is under vacuum and could remove material if not properly adhered.

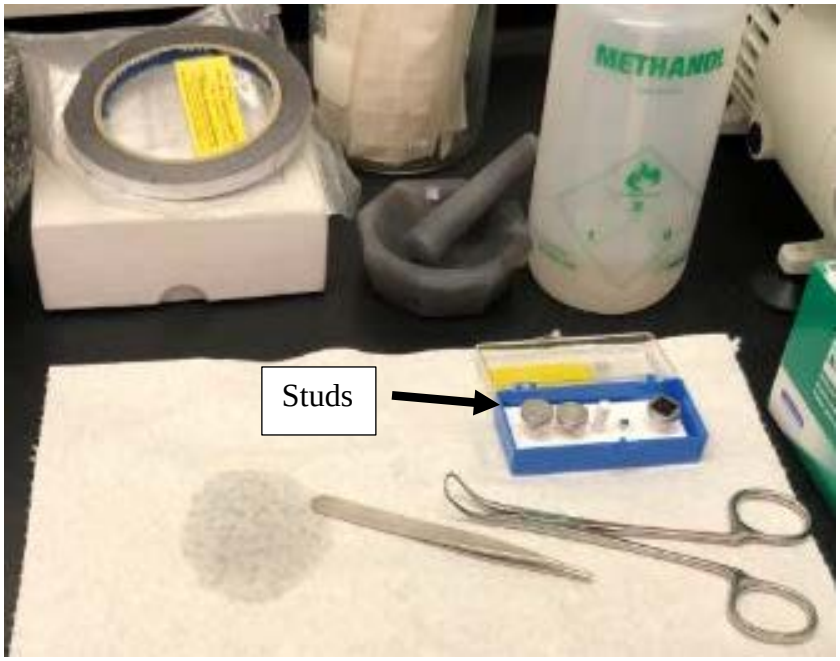

Figure 16. Carbon stud loading for Scanning Electron Microscope analyses using carbon tape to adhere the as is and modified carbon to the studs.

Analysis Method

An Excel (Microsoft Corp.) spreadsheet was used to analyze the concentration of DNT, BB and MB dyes. The UV-Vis data was copied to an Excel file that allowed it to be analyzed, as shown in Table 1, where the absorbance of UV light was converted to percentages of remaining concentrations. Sample analysis consisted of comparing initial concentration levels and the levels at each time interval (0-48 hrs), as shown in Equation

2. The total adsorption or removal was calculated using the initial concentration C_0 and the concentration at the given time C_t. Comparing the concentration over the same time gave an accurate comparison between samples by calculating the removal of contaminant.

$$\boldsymbol{removal = C_o - C_t} \qquad \text{Equation 2}$$

Summary

This chapter discussed the different materials used and how they were used, the electrochemical modification process, and the method used for analysis. The materials used were laid out in the manner in which they were utilized for the experiments. The processes taken using the equipment and how they worked corresponded to the method in which they were used. The analysis method taken using Excel was completed in order to answer the two stated research questions. Chapter IV will cover the analysis and results in detail to determine the effects of electrochemical modifications given the carbon species used.

IV. Analysis and Results

Chapter Overview

This chapter reviews and discusses the results of the electrochemical modification and bench bottle experiments. The experiments provided the data to support the researcher's hypotheses. The results are first reviewed and discussed to show the surface difference between the electrochemical modified and as is samples using SEM images. The data will be reviewed to show the impact that electrochemical modification has on adsorption capacity. The results of each method will be reviewed in individual sections, and supported with data and illustrations.

Scanning Electron Microscope Analysis

The SEM analyses were conducted by comparing the as is carbon species to their electrochemically modified counterparts. SEM images were taken at the Air Force Institute of Technology laboratory. Figure 17 through Figure 21 show the comparison between the as is and modified samples taken (Calgon Filtrasorb® 600 GAC, Evoqua AquaCarb® AC1240AW GAC, Evoqua AquaCarb® AC1230CX GAC, and CABOT NORIT GAC 400).

Figure 17 shows the SEM images of Applied Sciences Inc. PR-25-XT-PS CNF as is and modified. The first image on the left (as is CNF) shows the approximate average fiber diameter at 0.25 μm at 10 kV of electron energy. The image on the right (modified CNF) on Figure 17 shows little to no change in physical structure with similar average fiber diameter of 0.25 μm.

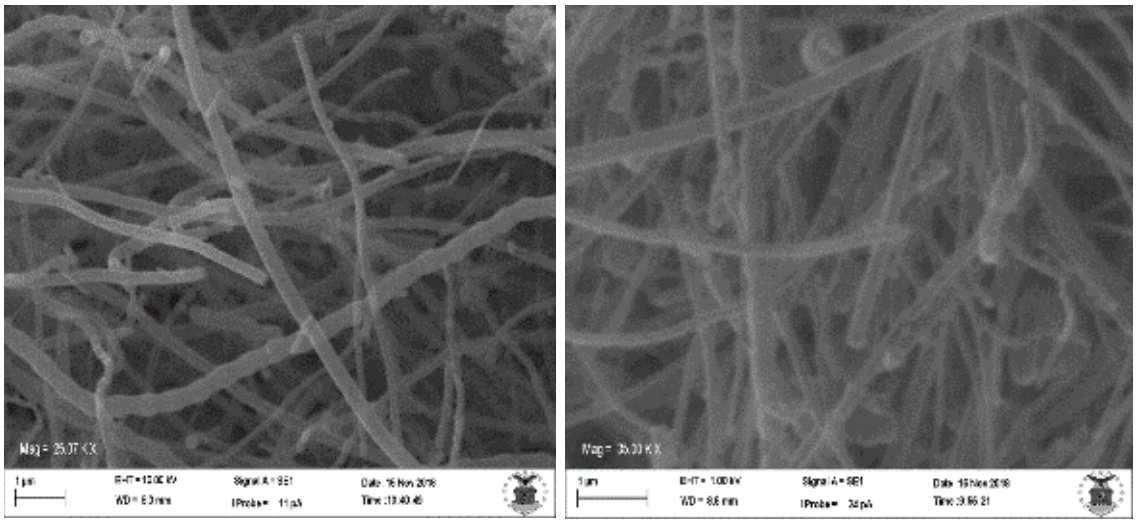

Figure 17. CNF as is (on the left) and modified CNF (on the right) SEM images showing the external surfaces and overall structure of the nanofibers magnified at 25.07 KX (on the left) and 35.00 KX (on the right) respectively.

Figure 18 displays the as is and modified Calgon F600 GAC images. From the image, the as is GAC sample on the right shows varying particles with average size of 2 μm on the surface of the carbon granule. The assumption is the particles are residual powdered activated carbon that was not washed away during the rinsing and decanting process. The image of the modified Calgon F600 GAC shows the large portion of residual particles are no longer on the surface; therefore, pores of the carbon are more visible.

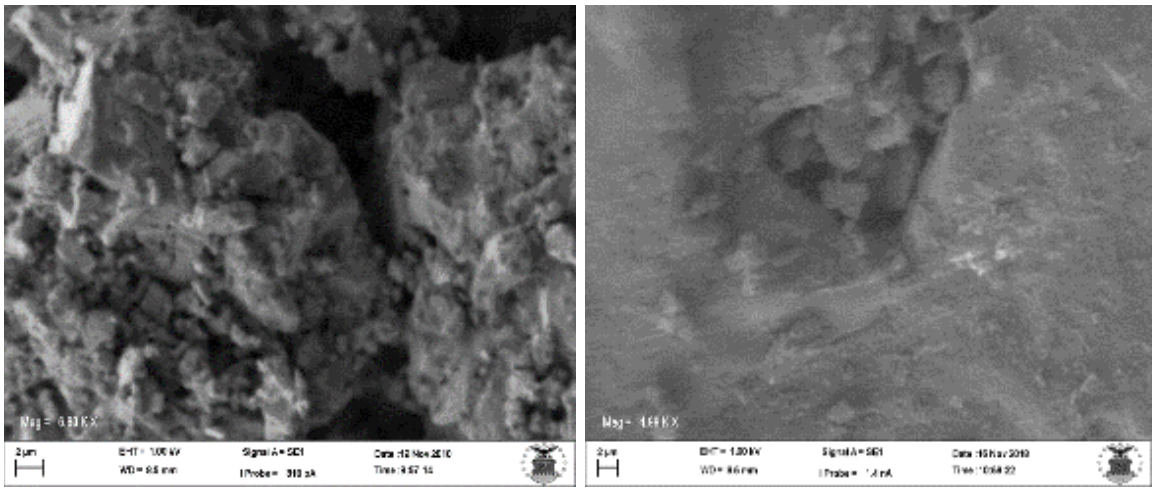

Figure 18. The Calgon F600 as is (on the left) and modified F600 (on the right) SEM images showing the external surfaces and overall structure of the GAC magnified at 6.88 KX (on the left) and 4.99 KX (on the right) respectively.

Figure 19 shows Evoqua UltraCarb® 1240 Carbon as is and modified side-by-side for comparison. The image on the left is of the as is sample and similar to that of the Calgon F600 as is sample in that particles of assumed residual carbon powder can be seen on the surface of the sample. The particles on the as is image range in size from 2 μm to up to 10 μm, which were much larger than the particles seen in the as is Calgon F600 GAC. The image on the right is of the modified Evoqua UltraCarb® 1240 Carbon, showing a reduced amount of particles. Overall, the average size of particles are less than 1 μm. The surface pores are also more visible and have an almost polished look when compared to the as is carbon species.

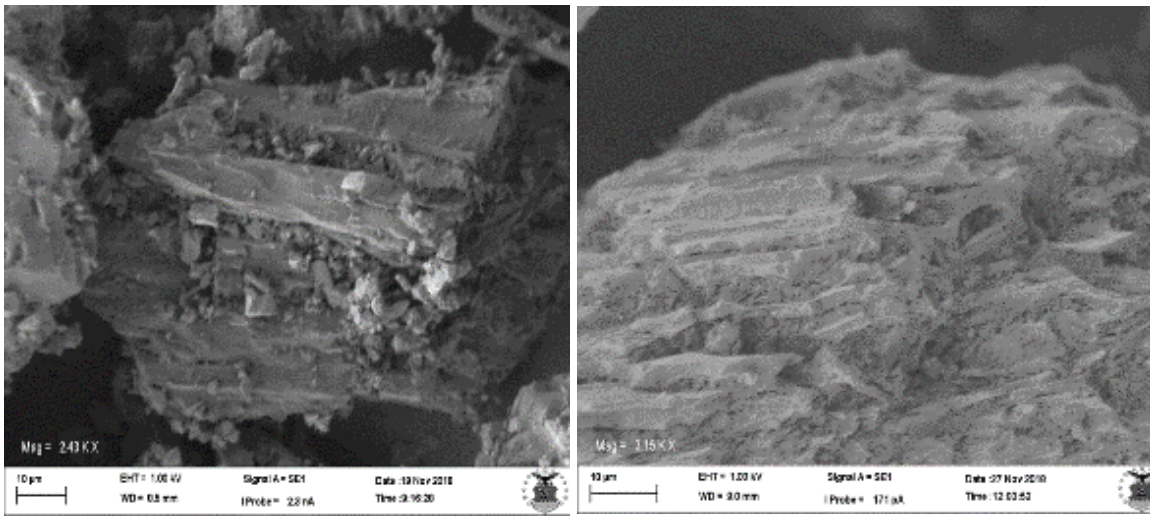

Figure 19. Evoqua UltraCarb® 1240 GAC as is (on the left) and modified (on the right) SEM images showing the external surfaces and overall structure of the GAC magnified at 2.43 KX (on the left) and 3.15 KX (on the right) respectively.

The images of Figure 20 show the Evoqua AquaCarb® AC1230CX GAC as is and modified. Similar to the as is Evoqua UltraCarb® 1240 Carbon, the as is AC1230CX GAC (on the left) had a wide range of residual particle sizes attached to the surface, ranging from 1 μm to 10 μm. After the electrochemical modification, the sample was much cleaner with almost no small particles attached to the surface as shown on the second image on the right of Figure 20. The pores are also more visible throughout the modified carbon species and the carbon as an almost polished look on the surface.

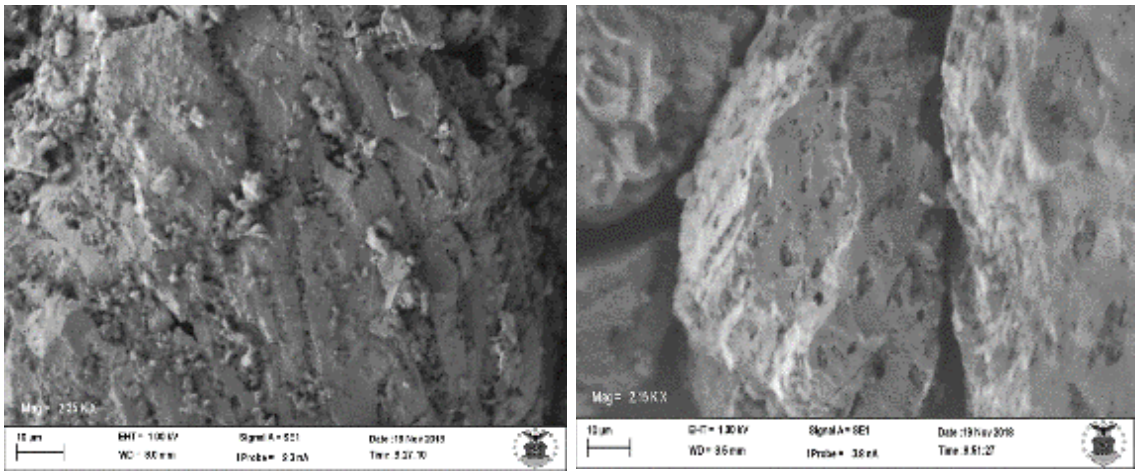

Figure 20. Evoqua AquaCarb® 1230CX as is (on the left) and modified (on the right) SEM images showing the external surfaces and overall structure of the GAC magnified at 2.35 KX (on the left) and 2.15 KX (on the right) respectively.

The CABOT NORIT GAC 400 images shown in Figure 21 are of the as is and modified carbon species. The particle size attached to granules were much smaller when compared to the other GAC specimens. With average particle sizes being less than 2 μm in the as is carbon sample as shown in the image on the left in Figure 21. The image on the right is of the modified carbon and shows a similar image to the as is when comparing the particle size attached to surface. Unlike the previous GACs, the NORIT GAC 400 shows minimal changes to the surface of the carbon with similar particle sizes and no polished carbon look as seen in the image of the modified GAC. A possible explanation of this is that the GAC was already acid treated by the manufacturer, therefore, the nitric acid was not as effective on the removal of the residual particles and surface polishing as compared to the others GAC specimens.

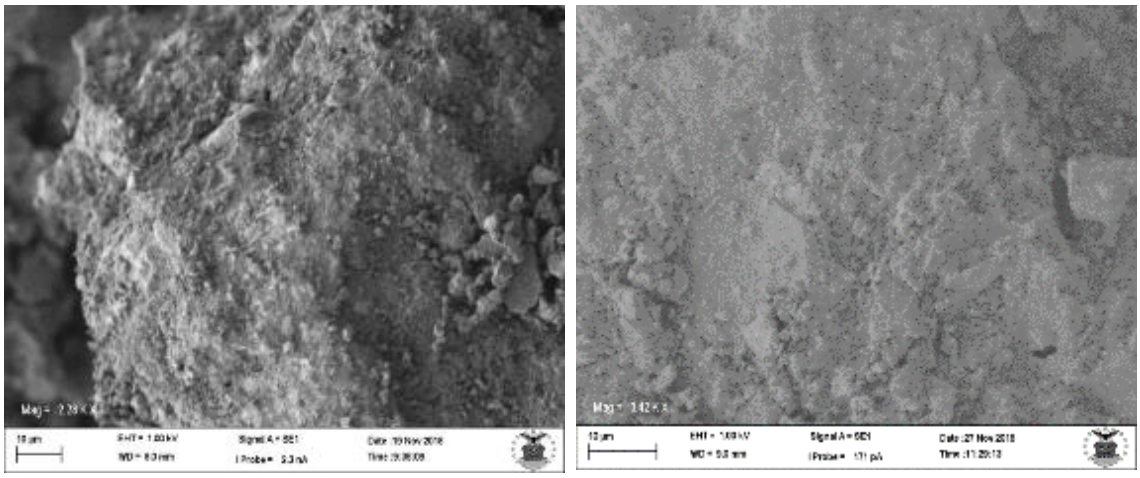

Figure 21. NORIT GAC 400 as is (on the left) and modified (on the right) SEM images showing the external surfaces and overall structure of the GAC magnified at 2.28 KX (on the left) and 3.42 KX (on the right) respectively.

DNT UV-Vis Calibration

A calibration curve was generated to achieve confidence in the precision and accuracy of the DNT measurement. The calibration curve was developed from five known solutions with 50%, 25%, 12.5%, 5%, and 0% concentrations. The solutions were made using a 100 ppm DNT stock solution diluted with the appropriate volume of deionized water. The absorbance is given by the UV-Vis at each concentration, providing a method to ensure accuracy of concentration values collected at the various time intervals at which samples were taken.

DNT removal by As Is and Modified Carbon

Comparison was accomplished by determining the total amount of contaminant adsorbed by each carbon species, as is and modified, over time as shown in Equation 2. Where removal in μg is the amount of adsorbate per mass unit of adsorbent at time t, C_o and C_t (mg) is the initial and at time t concentration of adsorbate, respectively, and t is

the amount of time in solution. The experiments were conducted in two parts to answer the first question. The initial part of the question was to determine if modification could enhance the carbon adsorption of DNT. This led to the second question of determining cationic and anionic properties of the carbon.

The initial experiments used a 10 ppm solution which was our standard DNT solution (4.33 mg) and 12.5 mg of as is carbon samples as shown in Figure 22. The standard test consisted of using the as is GAC samples to determine the adsorption capabilities of them prior to any modification. Performing the bench bottle test, the solutions and carbon species where allowed to mix for 48 hours and sampling was taken at the times of 0, 10, 20, 40, 80, 160, minutes and 24 and 48 hours. The standard tests were performed using Cabot NORIT GAC 400, Calgon F600, Evoqua AquaCarb® 1230CX, and Evoqua AquaCarb® 1240AW carbons.

As seen in Figure 22, at 12.5 mg of carbon the Evoqua AquaCarb® 1230CX carbon showed the most removal of DNT with 3.96 mg DNT adsorbed. The difference between the most adsorbent Evoqua AquaCarb® 1230CX and the least adsorbent NORIT 400 with 3.22 mg of DNT adsorption was 16%. The second best performing carbon was the AquaCarb® 1240AW with adsorption of 3.84 mg, which was 2% lower adsorption than the Evoqua 1230CX at the 48 hour sample point. The F600 carbon bench bottle experiment results were in the middle of the group with respect to final adsorption capacity, removing 3.53 mg of DNT. The largest difference seen from the figure is the rate at which the contaminant is adsorbed prior to the 24 hour measurement. The least adsorbent carbon within the timeframe of 0 to 160 minutes was the AquaCarb® 1240AW showing nearly 30% less adsorption of DNT.

Using Calgon F600 and Evoqua AquaCarb® 1230CX as the main carbons of study, multiple experiments were completed for statistical analysis of DNT adsorption. The error bars, where given, provide the standard deviation of the multiple experiments. The highest variance shown was for the Evoqua 1230CX from 0 to 160 minutes with an average of 16% among the experiments. The Evoqua 1230CX did however, have the least variance at the sampled times of 24 and 48 hours. The F600 variance was less with only a 10% difference as the highest between 0 and 160 minute samples. Unlike the Evoqua 1230CX, F600 continued to show slight variance throughout the 24 and 48 hour sampled solutions.

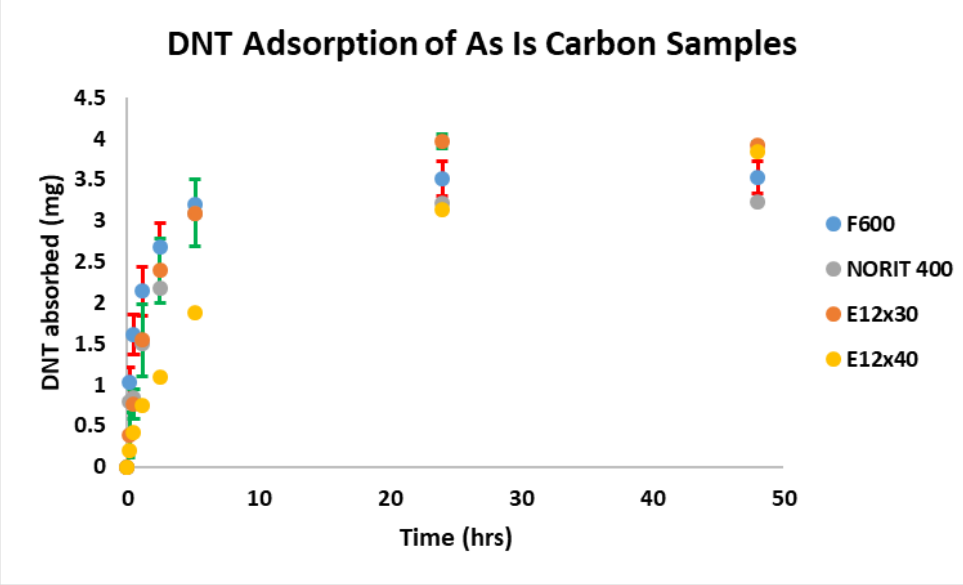

Figure 22. The image shows the as is carbon species with DNT solution adsorbed over time. The F600 and Evoqua 1230 show error bars given the multiple experiments conducted using these carbons.

The results shown on Figure 23 are those of the electrochemically modified carbons using the same 100% concentration of DNT solutions and time intervals as in the as is carbon experiments. Figure 23 shows all the modified carbons when compared to each other. Results of the NORIT 400 experiments showed that it was the most enhanced with adsorption of 4.28 mg of DNT or 98% removal compared to the 3.22 mg of DNT or 74% of the as is NORIT 400. The AquaCarb® 1240AW results showed it to be the second best enhanced carbon with the adsorption of 4.24 mg of DNT or 97% removal. Multiple experiments with modified Calgon F600 showed repeatability with less than 5% or 0.20 mg variance in the results of the total adsorbed DNT throughout all the sampled solutions. Evoqua AquaCarb® 1230CX showed large variance over multiple tests. The variance shown on the graph depicts over 100% variance in the adsorption of DNT for the Evoqua 1230CX over time. This finding led to further exploration as to why these specimens showed such high variance. Time dependence following modification was identified as a potential contributing factor. This also led to cationic and anionic dye experiments covered later in this chapter.

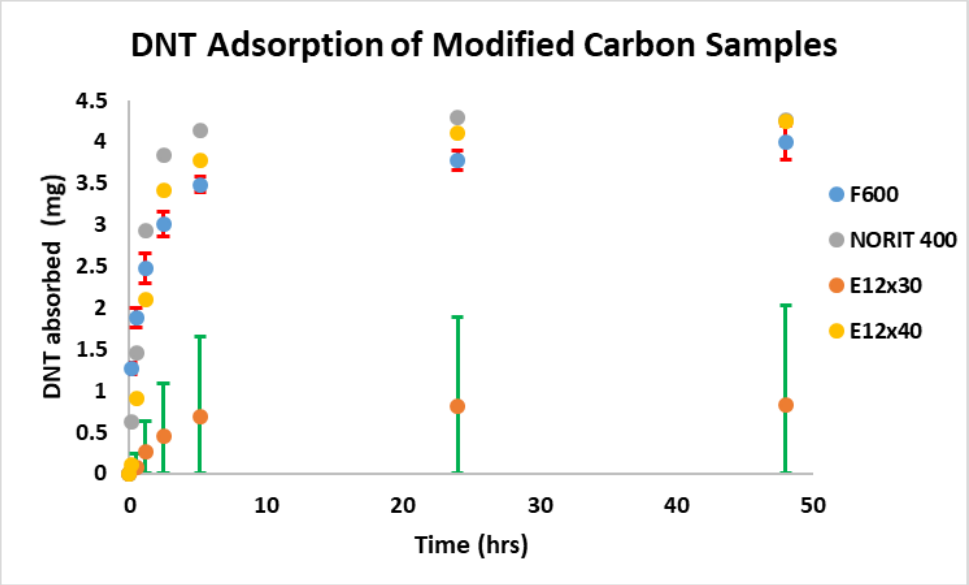

Figure 23. The image shows the modified GAC samples with DNT solution adsorbed over time. The modified F600 and Evoqua 1230 shown with error bars due to multiple experiments conducted with these samples.

The comparison of individual carbon species, such as NORIT GAC 400 as is and modified is shown in Figure 24. The data showed the modified carbon (orange dot) adsorbed DNT at a faster rate than the as is (blue dot) sample. Overall NORIT GAC 400 showed a greater adsorption capacity (nearly 25% increase) over the same duration. This may be partially attributable to having increased surface area as shown in the SEM images of Figure 21. Between the time of 0 minutes to final sampling at 48 hours, the GAC showed an increase in adsorption of DNT with the final adsorption being 4.26 mg as compared to the original adsorption of 3.22 mg of DNT. Therefore, showing that for the DNT contaminant, the electochemical modification of NORIT 400 did enhance the total adsorption capacity.

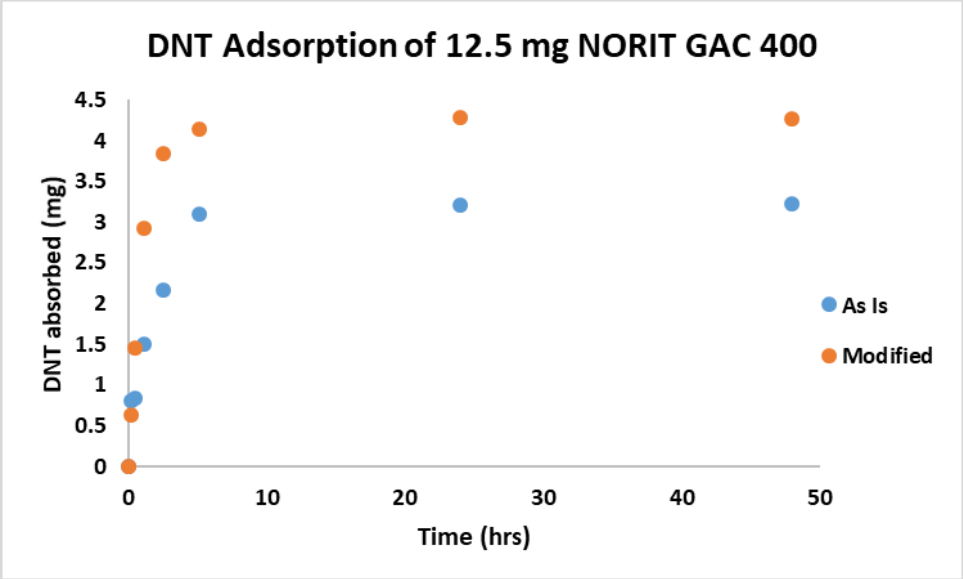

Figure 24. Image showing the direct comparison of DNT solution adsorbed over time between 12.5 mg of NORIT GAC 400 as is and modified sample.

The comparison of Evoqua AquaCarb® 1240AW as is and modified carbon experiments are depicted in Figure 25. An adsorption enhancement is seen throughout all the time intervals of 10 minutes to 48 hours. The adsorption of the modified carbon was on average 25% improved over that of the as is carbon as shown in Figure 25. The greatest enhancement in the modified carbon adsorption occurred at the 40 minute interval with a 43% (1.90 mg of DNT difference) increase over the as is carbon. Overall the modified carbon adsorption at the final time of 48 hrs was 9% greater than the as is carbon which was an increase of 0.4 mg of DNT adsorbed, indicating that the modification may increase the overall rate of adsorption substantially more than the overall adsorption capacity. Although the final adsorption capacity is only 9% improved, it would translate to a large adsorption capacity when considering carbon selection for treatment of large volumes of contaminated water.

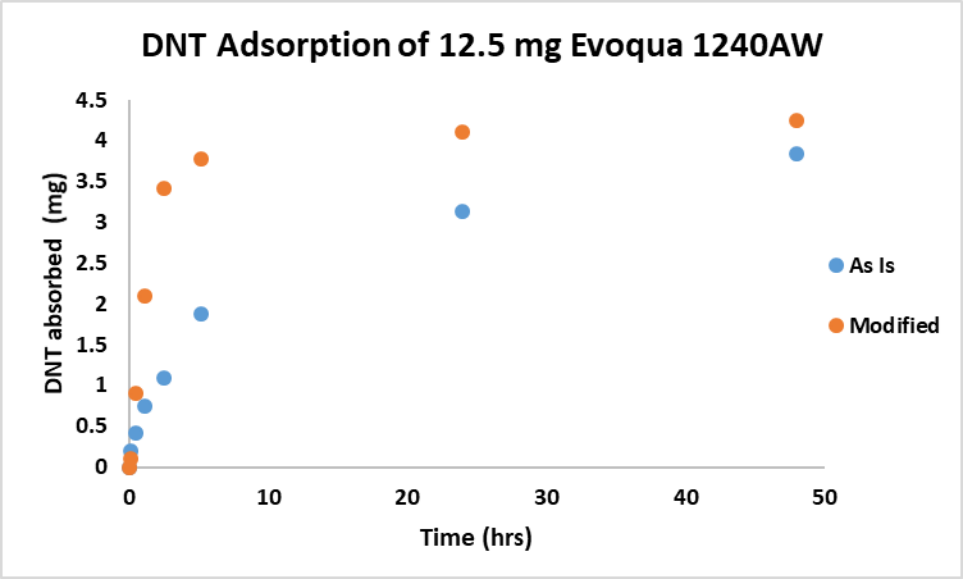

Figure 25. The comparison of DNT solution adsorbed over time between 12.5 mg of Evoqua 1240AW as is and modified sample.

Figure 26 shows the change in as is and modified Calgon F600 with approximately 10% enhancement through all time intervals. The comparative difference between Calgon F600 as is and modified carbons was not as significant as the previous carbons during the 10 minute to 160 minute sampling. The modified F600 kept the consistent 10% enhancement where the previous carbons, NORIT 400 and Evoqua 1240AW improved with an initial adsorption increase of 25% and 43%, respectively. The greatest difference is seen at the last sample taken at 48 hours where neither as is nor modified adsorption variance in experiments overlap.

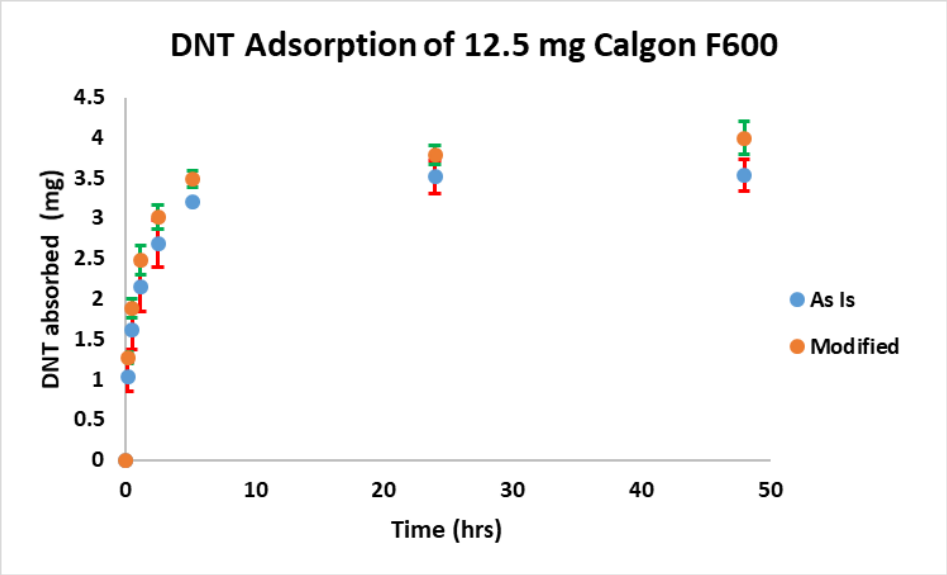

Figure 26. The comparison of DNT solution adsorbed over time between 12.5 mg of Calgon F600 as is and modified samples. Error bars are given to show the variance between multiple tests performed**.**

Results from the DNT adsorption using 12.5 mg of Evoqua AquaCarb® 1230CX as is and modified is shown in Figure 27. The adsorption properties of the GAC were greatly reduced to below 70% of original as is removal capability. From the raw data, the total adsorption of DNT with the as is GAC was 3.92 mg compared to the modified GAC of 0.83 mg. The graph shows a stagnant adsorption after 24 hours, with an adsorption increase of only 0.03 mg of DNT at the 48 hour sampled result. Further investigation led to the assumption that the time the GAC was stored after electrochemical modification may have contributed to large variance in adsorption readings. These results led to subsequent experiments of not only testing cationic and anionic properties, but also the effects of time after modification on the electrochemical modification treatment properties.

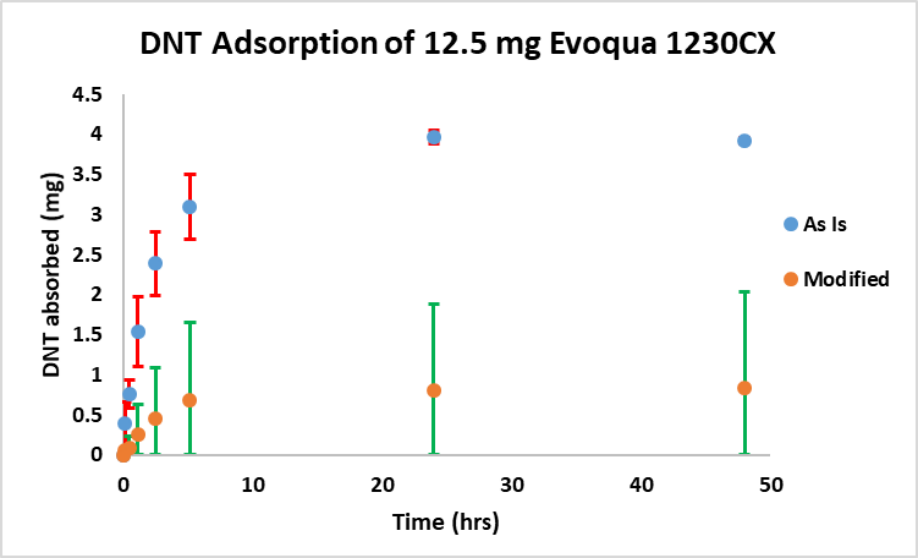

Figure 27. The graph shows the DNT adsorbed over time by 12.5 mg of Evoqua AquaCarb® 1230CX as is and modified. Large difference in multiple experiments led to further experiments to determine possible explanations.

BB and MB dye removal by As Is and Modified Evoqua AquaCarb® 1230CX

Further analysis of cationic and anionic dye adsorption was accomplished to determine if cationic or anionic properties of the Evoqua AquaCarb® 1230CX was degraded due to the large variance seen in the DNT experiments. The as is GAC was used with the 5 ppm (2.17mg) BB dye solution to show the anionic adsorption capability using 6 mg, 12.5 mg, and 18 mg of GAC as shown in Figure 28. The results showed that only 15% of total dye was removed at 18 mg carbon dosing and only 7% at 6 mg of carbon at the 48 hour sample time. Results of pilot studies showed that 12.5 mg of as is Calgon F600 could remove 90% of the BB dye, to give the comparison to show that carbon could remove the dye and the Evoqua AquaCarb® 1230CX did under perform. The results show that the Evoqua 1230CX GAC had little adsorption capability of the anionic dye, which could be a surrogate for other anionic contaminants.

A concern was noted with noise in the results of the multiple experiments using BB dye and varying masses of 1230CX carbon. The results show very little overall removal and noise in the data, indicating 1230CX aversion to adsorbing BB dye due to incompatible chemical or physical properties. The entire sampled tests (6 mg and 18 mg) resulted in similar adsorption readings from the 10 minutes to 160 minutes, where they would adsorb an amount of contaminant, then release part of the adsorbed amount on the next sampling as shown in Figures 28 through 30.

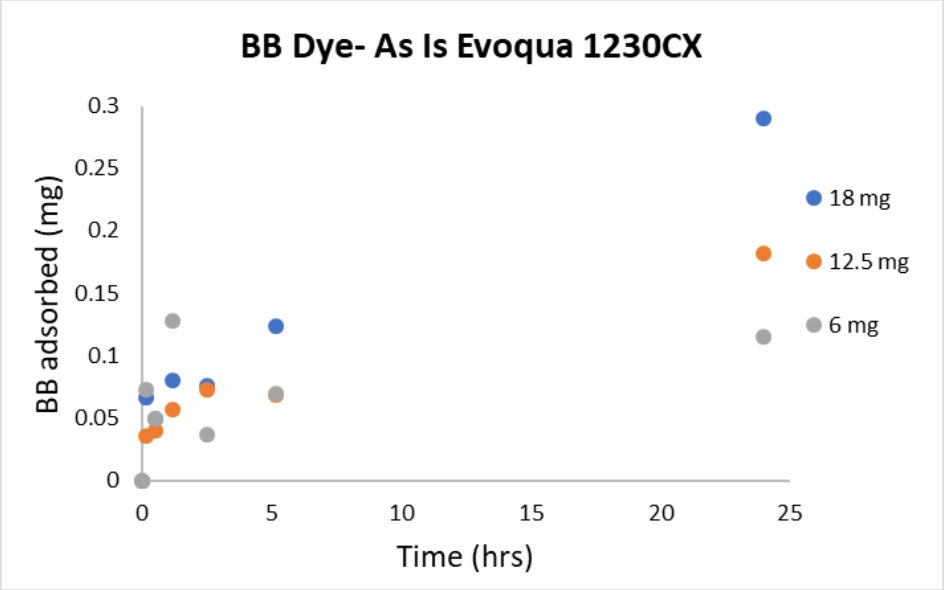

Figure 28. Graph shows the as is Evoqua AquaCarb® 1230CX adsorption of BB dye over time at multiple amounts of carbon samples (18 mg, 12.5 mg, and 6 mg).

The experiments using 6 mg of modified Evoqua AquaCarb® 1230CX GAC at days 1, 3, 5, and 7 are compared to the as is carbon results shown in Figure 29. Due to the large variance in DNT adsorption using the modified Evoqua 1230CX carbon, where the variance from time 0 to 48 hours was two to three times the adsorption at the same duration, the time after modification was used as another variable. The only difference in

the experiments were the time after modification, hence, the test with respect to time lapsed after carbon modification vs simply the time duration of the carbon in the bench bottle tests. From the graph, the variance in adsorption is seen with respect to the days from modification, with one of the largest changes being seen at the final sampling time of 24 hours where, as the days from modification increases so does the adsorption. Comparing final adsorption of the modified carbon shows the as is and Day 7 modified carbon adsorbed 0.033 mg and 0.030 mg, respectively. The results for modified Day 1 carbon adsorption or lack thereof, were the worst at 0 mg of BB dye.

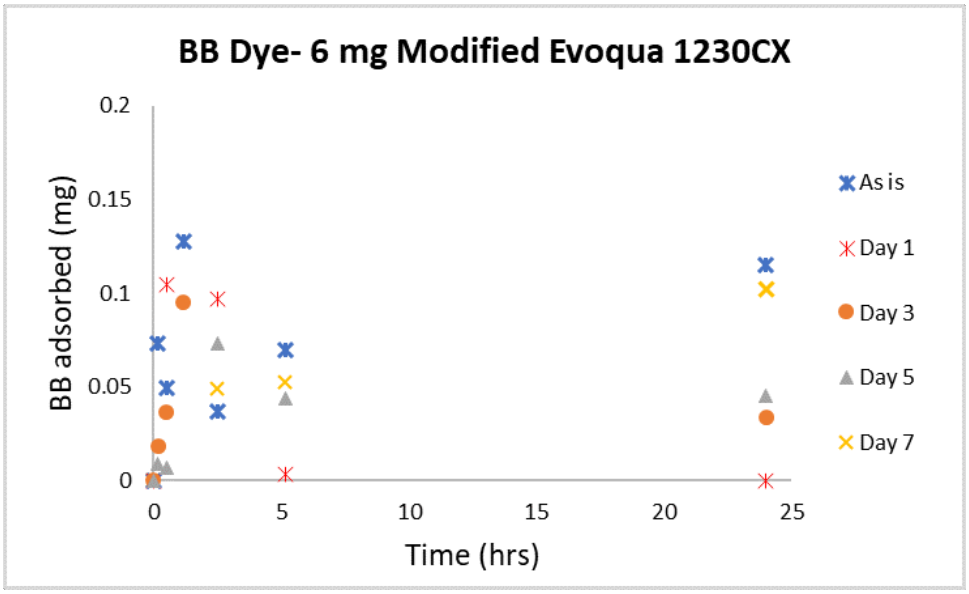

Figure 29. BB dye absorption by 6 mg of modified Evoqua 1230CX. Experiments were conducted at days 1, 3, 5, and 7 after electrochemical modification.

The result at 18 mg of modified Evoqua AquaCarb® 1230CX carbon were analyzed using the adsorption amount of BB dye over time (days 1, 3, 5, and 7) with respect to the as is GAC as shown in Figure 30. Similar to the modified GAC at 6 mg the results between the initial measurement of 10 minutes and 160 minutes were somewhat

noisy. The difference at 18 mg of modified carbon was the final adsorption of BB dye was similar to the previous as the days from modification increased so did the adsorption of BB dye. The results showed the adsorption increased in the following order from least to greatest adsorption, Day 5 (0.050 mg), Day 1 (0.054 mg), Day 3 (0.054 mg), Day 7 (0.074 mg) and as is carbon (0.090 mg).

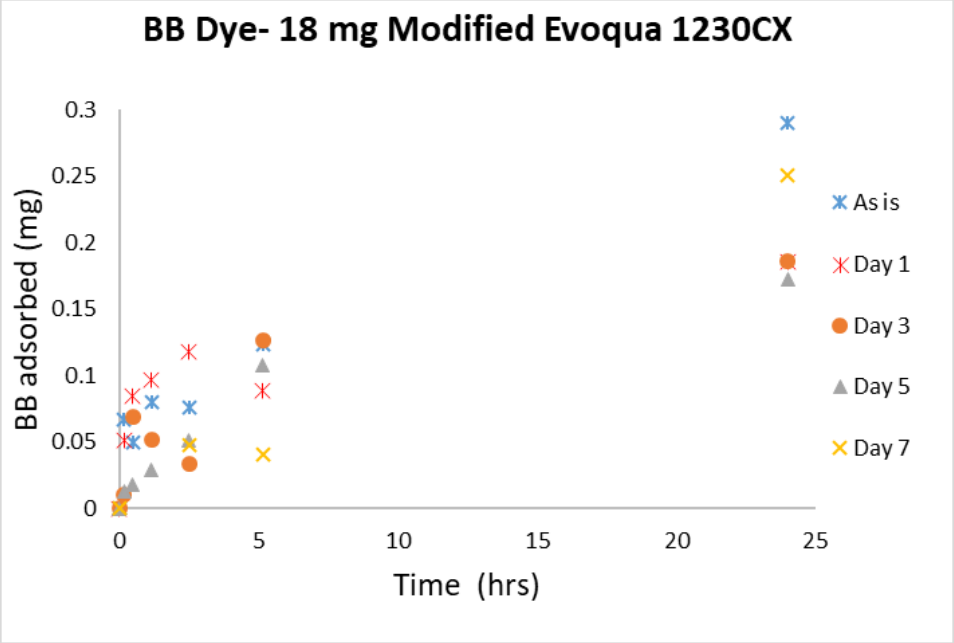

Figure 30. BB dye absorption by 18 mg of modified Evoqua 1230CX. Experiments were conducted at days 1, 3, 5, and 7 after electrochemical modification.

To determine cationic adsorption properties of as is and modified Evoqua AquaCarb® 1230CX GAC, MB dye was used in the experiments similar to the DNT and the BB dye bench bottle tests. Figure 31 shows the adsorption of MB dye over time after electrochemical modification with respect to 6 mg, 12.5 mg, and 18 mg of the as is GAC. Unlike the results from BB dye, MB dye showed to be more consistent throughout all the sampled results. At 6 mg of as is Evoqua AquaCarb® 1230CX, it adsorbed 50% of the

MB dye and at 18 mg the adsorption was over 99%. Results indicate that this GAC had better cationic adsorption properties than anionic in, as is form.

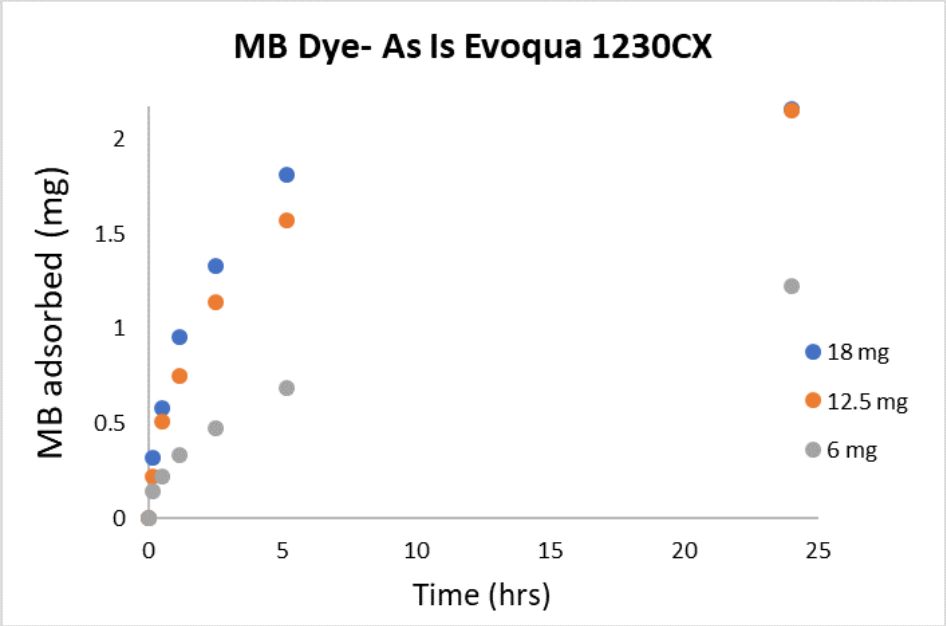

Figure 31. The graph shows the MB dye absorption by as is Evoqua AquaCarb® 1230CX. Experiments were conducted at 6 mg, 12.5 mg, and 18 mg of carbon to determine baseline of adsorption capability over a 24 hour duration.

Figure 32 shows the modified Evoqua AquaCarb® 1230CX with respect to time after modification and the as is carbon results. Compared to the as is carbon adsorption of MB dye, the modified carbon performed 8% better at 6 mg of modified GAC over the duration of the 7 days after modification than the as is carbon. The greatest improvement was seen at 7 days after modification showing an increase of 0.30 mg of MB adsorption over the as is GAC. The least enhancement was noted with modified carbon at Day 1 with 2% greater adsorption over the standard as is carbon.

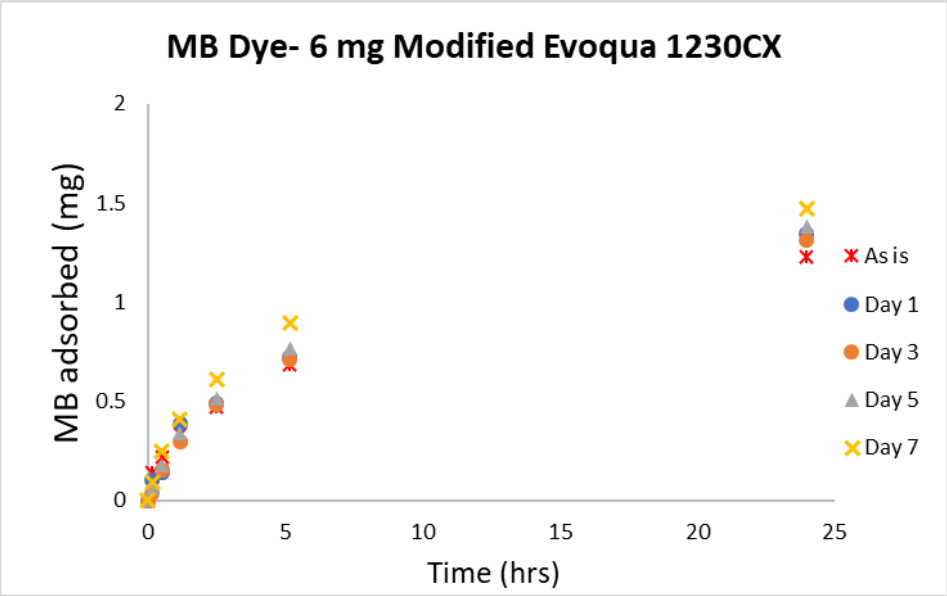

Figure 32. The MB dye absorption by 6 mg of modified Evoqua 1230CX is shown in this graph. Experiments were conducted at days 1, 3, 5, and 7 after electrochemical modification using the same time intervals as previous experiments (0, 10, 20, 40, 80, 160 minutes and 24 hours).

The comparison of the adsorption of as is and modified Evoqua AquaCarb® 1230CX at 12.5 mg with respect to days after electrochemical modification is shown in Figure 33. A decrease in adsorption over the 7 day time period after modification is shown in Figure 33, with the Day 5 result showing the highest adsorption at 3.15 mg, the same as the original as is carbon. The lowest adsorption of the modified carbon was Day 1 with only 2.09 mg or 66% adsorption of MB dye. Unlike the previous BB dye samples where the adsorption decreased drastically, the MB dye decrease was below 32% at Day 1 and 5% decrease at Day 7 for 12.5 mg of as is and modified GAC.

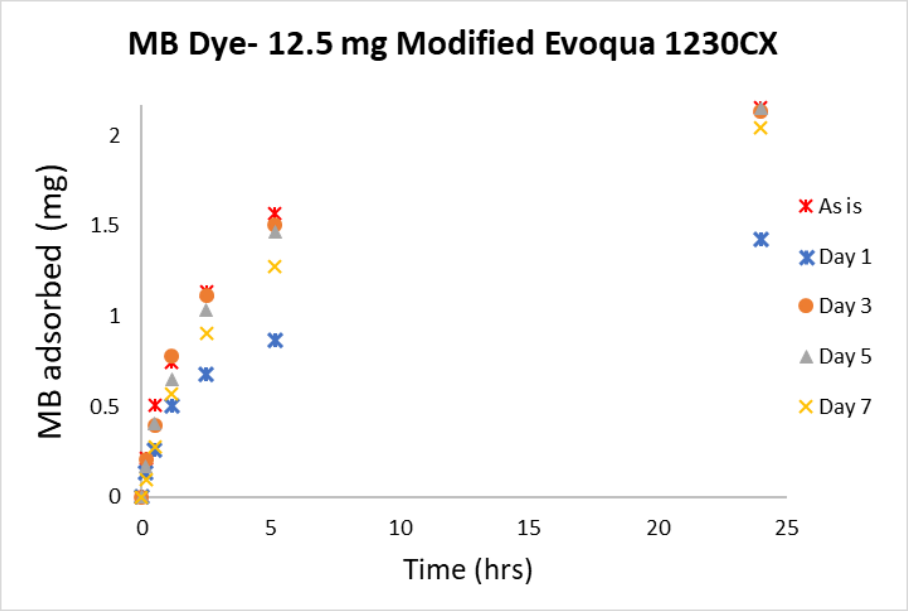

Figure 33. The MB dye adsorption by 12.5 mg of modified Evoqua AquaCarb® 1230CX. GAC shows a greater decrease below 5 hours than it does at the final sampling of 24 hours.

Figure 34 depicts the comparison of 18 mg of as is and modified Evoqua AquaCarb® 1230CX GAC, over time in the MB solution with respect to the days after the electrochemical modification occurred. The adsorption of MB dye changed less than 5% on average throughout the duration of the experiment. The final adsorption percentages of as is, Day 1, Day 3, Day 5, and Day 7 was over 99% for the MB dye. Similar to the previous experiments, the most change came under the 160 minute duration of sampling with the largest difference being at the 40 minute duration with a decrease of 18% adsorption or 0.58 mg MB dye. At the final sampling of 24 hours the adsorption of MB dye was within 1% of difference. Similarly to the BB dye experiments, this hints to the possibility that time after modification treatment may affect the adsorption characteristics for both anionic and cationic properties of the GAC. Additional

experiments of the remaining carbons would need to be completed to determine what mechanism affects the carbon species following modification.

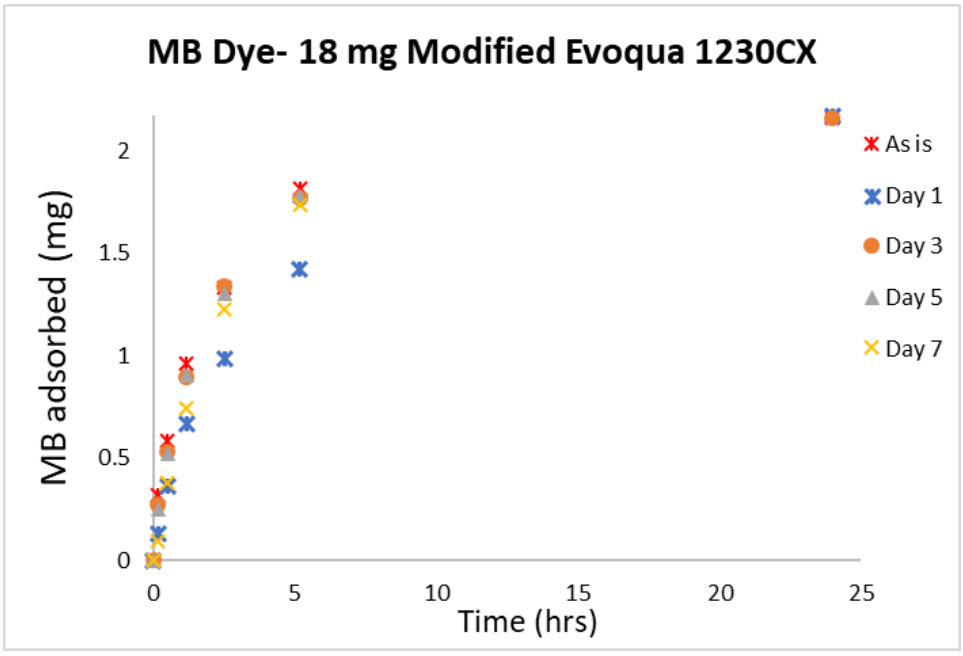

Figure 34. The MB dye adsorption by 18 mg of modified Evoqua AquaCarb® 1230CX over 24 hours of sampling. The graph shows a small decrease of adsorption capacity at 18 mg throughout the whole duration of sampling.

V. Conclusions and Recommendations

Chapter Overview

This chapter closes the research and findings from the literature review conducted for this thesis. It strives to answer the two research questions proposed which were investigated to the best ability of the researcher under the time constraint and resources available.

The objective of this research was to determine if electrochemical surface modification of carbon species could enhance the adsorption capability. An evaluation between the as is samples and the samples modified were made to determine the adsorption change, if any, when used to adsorb DNT, BB, and MB, as well as to see if the modification changes the ionic adsorption with respect to the cationic and anionic dyes.

Research Questions Answered

Research Question 1: Whether electrochemical surface modification can enhance the adsorption capabilities of various carbons using brilliant blue dye, methylene blue dye, and DNT as contaminants?

Partially. The results showed an increase in adsorption capacity in three of the four electrochemically modified carbons (NORIT GAC 400, Evoqua UltraCarb® 1240, GAC Calgon F600, in order of best to least improved). The modified Evoqua AquaCarb® 1230CX showed a decrease in adsorption for DNT, and BB dye with little to no change in the MB dye adsorption. The study overall does show that the treatment increases the adsorption capacity of the more dense carbons such as the bituminous coal. Although, due to the low adsorption of Applied Sciences Inc. PR-25-XT-PS CNF in the

pilot studies as is and modified, it was not further pursued as the others were. The results from the modified carbon tests showed nearly a 25% improvement when used in the 10 ppm DNT solution bench bottle test study within the 10 to 160 minute duration sampled.

Research Question 2: Whether the treatment enhances the adsorbent cationic or anionic capabilities?

Further research is needed to accurately determine by what mechanism the treatment modifies the chemistry of the carbon species used in the study. The effort to test cationic and anionic properties before and after treatment was only accomplished on the Evoqua AquaCarb® 1230CX. The results showed that anionic adsorption was negatively affected in the less dense coconut based carbon. The results also revealed that time after treatment affected the adsorption performance. Over a 7-day study after treatment, the results showed the anionic adsorption properties increased, but not to the original as is adsorption capability of the GAC. The cationic adsorption properties showed that the electrochemical modification had an increase of 10% adsorption within the first 160 minutes of testing and the final sampling time of 24 hours the concentration did not show an overall increase in adsorption capability.

Significance of Research

This research investigated the potential improvements to the efficiency of GAC samples when enhanced through electrochemical modification. As the concern for CECs will be ever present, there will be a continued need to study treatment technologies for these and other chemicals. Research of electrochemical modification of carbon may further

the capability to reduce the level of contaminants in the water. The significance of the research suggest that electrochemical modification does have the ability to modify carbon adsorption. Therefore, as the treatment is further studied and improved the ability to extend the carbon life in real world application can be possible.

Recommendations for Future Research

Additional research is recommended to determine the optimal time for the nitric acid solution bath. An optimized treatment process using electrochemical modification has the potential to improve the adsorption of carbons in order to reduce contamination from water sources with greater efficiency than currently employed carbons.

Further, additional research is recommended to determine the cationic and anionic characteristics of all the carbon species prior to and after treatment. Determining the cationic and anionic properties of the carbon could aid in understanding how and what chemicals they can adsorb for current and future contaminants.

Additionally, further research in the electrochemical modification procedures should be studied to improve the process. A database to determine whether to choose an off-the-shelf carbon versus having one specifically modified for certain contaminants could be established using the cost analysis and the results of future modified carbons. By using an additional treatment step, the costs associated with treatment and energy use should be further investigated to determine the cost of treatment versus adding a secondary type of treatment.

Summary

An electrochemical modification treatment process was developed and investigated to determine if potential enhancement of adsorption capabilities of sampled carbon could be improved. Adsorption capabilities were created through bench bottle tests using the as is GAC results and the modified GAC results of DNT, BB dye, and MB dye adsorption. Results showed that the coal based GACs adsorption were enhanced and the coconut GAC's adsorption were degraded following modification. The coal based GAC showed a faster adsorption rate from time 0 to 160 minutes, with close to 25% increase in adsorption for all coal based carbons based on time and amount of contaminant use in the study. The coconut based GAC showed an overall degradation of adsorption, even more so with respect to the anionic BB dye contaminant. The overall effect of modification over time was not studied in great depth, but is something to consider; results revealed that as time progressed after treatment, the coconut GAC began to improve back to its original adsorption capability. Therefore, continued research on electrochemical modification of carbon is needed to determine the total effects of the treatment.

Overall, the electrochemical modification proposed and researched in this study found some significant results, such as successful enhancement in adsorption in the coal based carbons and the reduction of adsorption for the coconut based carbon, with improvement back toward baseline over time. This indicates that possible modification of the procedures for the electrochemical modification accomplished in this study could result in overall improvement in adsorption capacity for multiple carbon species. Further refining procedures could lead to the removal of current and future CECs due to the ever-changing chemical properties used in today's manufacturing of products.

Appendix A: UV-Vis DNT adsorption

12.5 mg of F600 with 10 PPM DNT solution

F0		F1		F2		F3		F4		F5		F6		F7		F8	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
259.9859	0.551018	259.9859	0.443725	259.9859	0.384116	259.9859	0.326546	259.9859	0.257659	259.9859	0.203248	259.9859	0.136331	259.9859	0.133791	259.9859	0.131084
259.0019	0.558463	259.0019	0.450118	259.0019	0.389573	259.0019	0.331531	259.0019	0.26176	259.0019	0.206559	259.0019	0.139003	259.0019	0.136242	259.0019	0.133513
258.0179	0.567376	258.0179	0.457687	258.0179	0.396648	258.0179	0.337521	258.0179	0.266219	258.0179	0.210766	258.0179	0.142094	258.0179	0.139384	258.0179	0.13655
256.9944	0.574623	256.9944	0.463685	256.9944	0.401667	256.9944	0.342398	256.9944	0.270689	256.9944	0.213843	256.9944	0.144657	256.9944	0.141775	256.9944	0.139019
256.0101	0.581443	256.0101	0.46937	256.0101	0.406862	256.0101	0.346492	256.0101	0.274139	256.0101	0.217002	256.0101	0.147007	256.0101	0.144479	256.0101	0.141373
254.9865	0.587396	254.9865	0.474316	254.9865	0.411283	254.9865	0.350482	254.9865	0.277557	254.9865	0.219947	254.9865	0.149279	254.9865	0.146525	254.9865	0.143381
254.002	0.59222	254.002	0.478087	254.002	0.414898	254.002	0.353696	254.002	0.280003	254.002	0.222179	254.002	0.15071	254.002	0.148083	254.002	0.145085
253.0175	0.596424	253.0175	0.481714	253.0175	0.418	253.0175	0.356698	253.0175	0.282487	253.0175	0.224712	253.0175	0.152513	253.0175	0.149842	253.0175	0.146609
251.9935	0.597795	251.9935	0.483152	251.9935	0.419512	251.9935	0.35784	251.9935	0.283532	251.9935	0.225473	251.9935	0.153052	251.9935	0.150212	251.9935	0.147343
251.0087	0.600045	251.0087	0.484953	251.0087	0.421183	251.0087	0.359906	251.0087	0.284922	251.0087	0.227323	251.0087	0.154432	251.0087	0.151567	251.0087	0.148705
249.9845	0.600975	249.9845	0.485693	249.9845	0.422607	249.9845	0.360793	249.9845	0.285979	249.9845	0.228815	249.9845	0.155657	249.9845	0.152854	249.9845	0.149654
248.9996	0.601787	248.9996	0.486947	248.9996	0.423669	248.9996	0.362571	248.9996	0.28761	248.9996	0.231137	248.9996	0.157445	248.9996	0.154379	248.9996	0.151512
248.0146	0.599252	248.0146	0.485513	248.0146	0.422655	248.0146	0.361994	248.0146	0.287056	248.0146	0.231543	248.0146	0.157448	248.0146	0.154784	248.0146	0.151648
246.9901	0.595737	246.9901	0.48265	246.9901	0.420034	246.9901	0.360077	246.9901	0.285482	246.9901	0.230704	246.9901	0.156565	246.9901	0.153691	246.9901	0.150752
246.0049	0.590434	246.0049	0.478355	246.0049	0.416869	246.0049	0.357122	246.0049	0.282879	246.0049	0.229247	246.0049	0.154986	246.0049	0.152267	246.0049	0.149283
245.0196	0.585635	245.0196	0.474944	245.0196	0.414533	245.0196	0.355077	245.0196	0.281639	245.0196	0.229267	245.0196	0.155012	245.0196	0.15206	245.0196	0.149144

12.5 mg of F600 with 10 PPM DNT solution

2F60		2F61		2F62		2F63		2F64		2F65		2F66		2F67	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
260.0008	0.640737	260.0008	0.490988	260.0008	0.392403	260.0008	0.300055	260.0008	0.209991	260.0008	0.166928	260.0008	0.089375	260.0008	0.091272
259.017	0.649461	259.017	0.49758	259.017	0.398126	259.017	0.30434	259.017	0.213289	259.017	0.169	259.017	0.091538	259.017	0.093031
257.9937	0.659136	257.9937	0.505241	257.9937	0.404336	257.9937	0.309523	257.9937	0.217182	257.9937	0.172378	257.9937	0.093556	257.9937	0.095183
257.0096	0.667132	257.0096	0.51171	257.0096	0.409819	257.0096	0.313877	257.0096	0.2205	257.0096	0.174808	257.0096	0.095255	257.0096	0.096852
255.9861	0.674769	255.9861	0.517619	255.9861	0.414551	255.9861	0.317703	255.9861	0.223137	255.9861	0.177329	255.9861	0.096717	255.9861	0.098294
255.0019	0.681207	255.0019	0.522573	255.0019	0.418649	255.0019	0.321173	255.0019	0.225833	255.0019	0.17932	255.0019	0.097974	255.0019	0.099796
254.0176	0.686196	254.0176	0.526233	254.0176	0.421376	254.0176	0.323809	254.0176	0.227666	254.0176	0.180628	254.0176	0.098262	254.0176	0.100635
252.9938	0.690167	252.9938	0.529953	252.9938	0.424197	252.9938	0.326007	252.9938	0.229191	252.9938	0.182266	252.9938	0.09897	252.9938	0.101416
252.0093	0.692942	252.0093	0.531511	252.0093	0.425617	252.0093	0.326869	252.0093	0.229582	252.0093	0.182085	252.0093	0.09964	252.0093	0.1015
250.9853	0.694338	250.9853	0.532721	250.9853	0.426771	250.9853	0.327887	250.9853	0.230523	250.9853	0.182958	250.9853	0.100285	250.9853	0.102159
250.0005	0.694524	250.0005	0.532763	250.0005	0.426693	250.0005	0.328478	250.0005	0.231034	250.0005	0.183757	250.0005	0.100223	250.0005	0.102787
249.0158	0.695099	249.0158	0.533115	249.0158	0.427078	249.0158	0.329403	249.0158	0.231769	249.0158	0.184909	249.0158	0.101304	249.0158	0.104069
247.9915	0.691614	247.9915	0.530149	247.9915	0.425111	247.9915	0.328009	247.9915	0.230862	247.9915	0.184298	247.9915	0.100915	247.9915	0.103822
247.0065	0.687743	247.0065	0.526897	247.0065	0.422534	247.0065	0.325577	247.0065	0.228948	247.0065	0.18199	247.0065	0.100608	247.0065	0.102876
245.9819	0.681684	245.9819	0.521571	245.9819	0.418127	245.9819	0.321768	245.9819	0.225824	245.9819	0.179222	245.9819	0.098887	245.9819	0.100998
244.9967	0.675318	244.9967	0.515937	244.9967	0.41386	244.9967	0.31893	244.9967	0.223712	244.9967	0.178302	244.9967	0.097882	244.9967	0.100646

12.5 mg of F600 with 10 PPM DNT solution

1F60		1F61		1F62		1F63		1F64		1F65		1F66		1F67	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
260.0008	0.650773	260.0008	0.460305	260.0008	0.367334	260.0008	0.285308	260.0008	0.215848	260.0008	0.166772	260.0008	0.107248	260.0008	0.099109
259.017	0.659741	259.017	0.466092	259.017	0.372639	259.017	0.290047	259.017	0.218875	259.017	0.169339	259.017	0.109451	259.017	0.10108
257.9937	0.669062	257.9937	0.473865	257.9937	0.378859	257.9937	0.294794	257.9937	0.222936	257.9937	0.172661	257.9937	0.111737	257.9937	0.103276
257.0096	0.677526	257.0096	0.479909	257.0096	0.383813	257.0096	0.298922	257.0096	0.226048	257.0096	0.17502	257.0096	0.113647	257.0096	0.10527
255.9861	0.68518	255.9861	0.485293	255.9861	0.388481	255.9861	0.302793	255.9861	0.229309	255.9861	0.177555	255.9861	0.115299	255.9861	0.106695
255.0019	0.691647	255.0019	0.490293	255.0019	0.392807	255.0019	0.305816	255.0019	0.231791	255.0019	0.179714	255.0019	0.116785	255.0019	0.108086
254.0176	0.696854	254.0176	0.493892	254.0176	0.39548	254.0176	0.308235	254.0176	0.2337	254.0176	0.181011	254.0176	0.117434	254.0176	0.108788
252.9938	0.700865	252.9938	0.496609	252.9938	0.398197	252.9938	0.310326	252.9938	0.23584	252.9938	0.182102	252.9938	0.118347	252.9938	0.109587
252.0093	0.703364	252.0093	0.498129	252.0093	0.39901	252.0093	0.311476	252.0093	0.235561	252.0093	0.182338	252.0093	0.119047	252.0093	0.110199
250.9853	0.70481	250.9853	0.499743	250.9853	0.400322	250.9853	0.312523	250.9853	0.236696	250.9853	0.183296	250.9853	0.119672	250.9853	0.110648
250.0005	0.704676	250.0005	0.499831	250.0005	0.400925	250.0005	0.312758	250.0005	0.237422	250.0005	0.183765	250.0005	0.119723	250.0005	0.110963
249.0158	0.704714	249.0158	0.500415	249.0158	0.401495	249.0158	0.313416	249.0158	0.238414	249.0158	0.18478	249.0158	0.120955	249.0158	0.112252
247.9915	0.701231	247.9915	0.498097	247.9915	0.399768	247.9915	0.311996	247.9915	0.237304	247.9915	0.183955	247.9915	0.120449	247.9915	0.111519
247.0065	0.697254	247.0065	0.494975	247.0065	0.396579	247.0065	0.310252	247.0065	0.234921	247.0065	0.182121	247.0065	0.119872	247.0065	0.110969
245.9819	0.691184	245.9819	0.48955	245.9819	0.392363	245.9819	0.30689	245.9819	0.231631	245.9819	0.179537	245.9819	0.117834	245.9819	0.109187
244.9967	0.683502	244.9967	0.484824	244.9967	0.388364	244.9967	0.304053	244.9967	0.230082	244.9967	0.177985	244.9967	0.116612	244.9967	0.108244

12.5 mg of Norit 400 with 10 PPM DNT solution

N0		N1		N2		N3		N4		N5		N6		N7		N8	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
259.9859	0.612035	259.9859	0.497455	259.9859	0.491051	259.9859	0.3963	259.9859	0.300613	259.9859	0.258064	259.9859	0.168636	259.9859	0.150544	259.9859	0.149549
259.0019	0.62044	259.0019	0.504551	259.0019	0.49822	259.0019	0.401906	259.0019	0.305063	259.0019	0.262147	259.0019	0.171578	259.0019	0.153215	259.0019	0.152291
258.0179	0.630408	258.0179	0.512644	258.0179	0.506166	258.0179	0.409069	258.0179	0.310792	258.0179	0.266902	258.0179	0.174869	258.0179	0.156619	258.0179	0.155571
256.9944	0.638587	256.9944	0.51933	256.9944	0.512729	256.9944	0.414372	256.9944	0.315172	256.9944	0.270826	256.9944	0.177965	256.9944	0.159261	256.9944	0.158398
256.0101	0.645531	256.0101	0.525645	256.0101	0.519137	256.0101	0.41978	256.0101	0.319408	256.0101	0.274727	256.0101	0.180622	256.0101	0.161661	256.0101	0.160723
254.9865	0.652502	254.9865	0.53117	254.9865	0.524807	254.9865	0.42452	254.9865	0.322773	254.9865	0.277892	254.9865	0.183188	254.9865	0.164238	254.9865	0.163202
254.002	0.657549	254.002	0.535604	254.002	0.528728	254.002	0.4279	254.002	0.325909	254.002	0.280489	254.002	0.185174	254.002	0.166143	254.002	0.16506
253.0175	0.662213	253.0175	0.539117	253.0175	0.532747	253.0175	0.431765	253.0175	0.328584	253.0175	0.283166	253.0175	0.186953	253.0175	0.168046	253.0175	0.166711
251.9935	0.664119	251.9935	0.540955	251.9935	0.534539	251.9935	0.432874	251.9935	0.329529	251.9935	0.284612	251.9935	0.187544	251.9935	0.168338	251.9935	0.167003
251.0087	0.665861	251.0087	0.542851	251.0087	0.536483	251.0087	0.434805	251.0087	0.331336	251.0087	0.286201	251.0087	0.188873	251.0087	0.169644	251.0087	0.168604
249.9845	0.666953	249.9845	0.5435	249.9845	0.5378	249.9845	0.436166	249.9845	0.332469	249.9845	0.287604	249.9845	0.189955	249.9845	0.170986	249.9845	0.169394
248.9996	0.667527	248.9996	0.544306	248.9996	0.538953	248.9996	0.437519	248.9996	0.333603	248.9996	0.289636	248.9996	0.191522	248.9996	0.172762	248.9996	0.171464
248.0146	0.664948	248.0146	0.542675	248.0146	0.537244	248.0146	0.436236	248.0146	0.332985	248.0146	0.289629	248.0146	0.191698	248.0146	0.17292	248.0146	0.171441
246.9901	0.660693	246.9901	0.539173	246.9901	0.534098	246.9901	0.434077	246.9901	0.331043	246.9901	0.288621	246.9901	0.190651	246.9901	0.171852	246.9901	0.170458
246.0049	0.655291	246.0049	0.534924	246.0049	0.529692	246.0049	0.430546	246.0049	0.328096	246.0049	0.286627	246.0049	0.188727	246.0049	0.170053	246.0049	0.168804
245.0196	0.649547	245.0196	0.530538	245.0196	0.526146	245.0196	0.427737	245.0196	0.325877	245.0196	0.285759	245.0196	0.188148	245.0196	0.169721	245.0196	0.168338

12.5 mg Evoqua 12x30 original with 10 PPM DNT solution																
		E31		E32		E33		E34		E35		E36		E37		E38	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
260.0154	0.621331	260.0099	0.513111	260.0099	0.474033	260.0099	0.314448	260.0099	0.196572	260.0099	0.091006	260.0099	0.031197	260.0099	0.035107	260.0099	0.043388
258.9921	0.630147	258.9867	0.520913	258.9867	0.481386	258.9867	0.319786	258.9867	0.200766	258.9867	0.093222	258.9867	0.0326	258.9867	0.036477	258.9867	0.044843
258.0082	0.640746	258.0027	0.529127	258.0027	0.489048	258.0027	0.325302	258.0027	0.204456	258.0027	0.095453	258.0027	0.034201	258.0027	0.038177	258.0027	0.046559
256.9848	0.648096	257.0187	0.535649	257.0187	0.495166	257.0187	0.329821	257.0187	0.207478	257.0187	0.097574	257.0187	0.03563	257.0187	0.039477	257.0187	0.048234
256.0007	0.655294	255.9953	0.542088	255.9953	0.501268	255.9953	0.33375	255.9953	0.210354	255.9953	0.099638	255.9953	0.036952	255.9953	0.040841	255.9953	0.04939
255.0165	0.66179	255.011	0.547545	255.011	0.506335	255.011	0.337621	255.011	0.212941	255.011	0.101409	255.011	0.038205	255.011	0.041944	255.011	0.050617
253.9927	0.667458	253.9873	0.552052	253.9873	0.510551	253.9873	0.340611	253.9873	0.214892	253.9873	0.102551	253.9873	0.038937	253.9873	0.042963	253.9873	0.05149
253.0083	0.671565	253.0029	0.555814	253.0029	0.51412	253.0029	0.343059	253.0029	0.216235	253.0029	0.103588	253.0029	0.040022	253.0029	0.044048	253.0029	0.052367
251.9845	0.67363	252.0184	0.557295	252.0184	0.515672	252.0184	0.344389	252.0184	0.217785	252.0184	0.10402	252.0184	0.04041	252.0184	0.044282	252.0184	0.052769
250.9998	0.675382	250.9944	0.559144	250.9944	0.517674	250.9944	0.345858	250.9944	0.219328	250.9944	0.105289	250.9944	0.041426	250.9944	0.045704	250.9944	0.054066
250.0151	0.67618	250.0097	0.560062	250.0097	0.518252	250.0097	0.346905	250.0097	0.219744	250.0097	0.106376	250.0097	0.042634	250.0097	0.046804	250.0097	0.05491
248.9909	0.676281	248.9855	0.560511	248.9855	0.519308	248.9855	0.347882	248.9855	0.221367	248.9855	0.108137	248.9855	0.044792	248.9855	0.049264	248.9855	0.05698
248.006	0.67351	248.0006	0.558467	248.0006	0.517288	248.0006	0.347002	248.0006	0.22117	248.0006	0.108456	248.0006	0.045704	248.0006	0.050106	248.0006	0.057543
246.9816	0.669604	247.0156	0.554944	247.0156	0.514237	247.0156	0.345152	247.0156	0.221075	247.0156	0.107649	247.0156	0.045275	247.0156	0.049917	247.0156	0.057333
245.9965	0.663563	245.9911	0.550584	245.9911	0.510156	245.9911	0.342337	245.9911	0.219824	245.9911	0.106548	245.9911	0.044778	245.9911	0.049675	245.9911	0.056675
245.0113	0.65764	245.0059	0.545591	245.0059	0.505954	245.0059	0.339556	245.0059	0.218431	245.0059	0.106799	245.0059	0.045825	245.0059	0.051082	245.0059	0.057462

12.5 mg Evoqua 12x30 original with 10 PPM DNT solution															
E30		E31		E32		E33		E34		E35		E36		E37	
Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs	Wavelength	Abs
260.0154	0.567497	260.0154	0.557249	260.0154	0.487773	260.0154	0.428135	260.0154	0.307539	260.0154	0.212995	260.0154	0.0386	260.0154	0.054525
258.9921	0.57555	258.9921	0.56512	258.9921	0.494621	258.9921	0.434231	258.9921	0.312044	258.9921	0.21575	258.9921	0.039538	258.9921	0.055556
258.0082	0.584144	258.0082	0.573564	258.0082	0.501775	258.0082	0.440808	258.0082	0.316886	258.0082	0.219556	258.0082	0.04055	258.0082	0.056661
256.9848	0.590664	256.9848	0.580206	256.9848	0.507894	256.9848	0.446217	256.9848	0.320698	256.9848	0.222619	256.9848	0.041458	256.9848	0.057956
256.0007	0.597184	256.0007	0.586467	256.0007	0.513612	256.0007	0.451408	256.0007	0.324453	256.0007	0.225044	256.0007	0.042043	256.0007	0.058672
255.0165	0.60229	255.0165	0.591735	255.0165	0.518133	255.0165	0.455135	255.0165	0.327341	255.0165	0.227337	255.0165	0.042536	255.0165	0.059293
253.9927	0.606539	253.9927	0.595981	253.9927	0.521864	253.9927	0.458514	253.9927	0.329661	253.9927	0.229068	253.9927	0.04254	253.9927	0.059211
253.0083	0.60978	253.0083	0.599436	253.0083	0.524866	253.0083	0.461124	253.0083	0.331477	253.0083	0.230608	253.0083	0.042843	253.0083	0.059826
251.9845	0.611654	251.9845	0.601443	251.9845	0.526357	251.9845	0.462802	251.9845	0.332507	251.9845	0.230944	251.9845	0.043158	251.9845	0.060146
250.9998	0.61283	250.9998	0.602573	250.9998	0.527548	250.9998	0.463921	250.9998	0.333403	250.9998	0.231814	250.9998	0.043167	250.9998	0.060339
250.0151	0.612828	250.0151	0.602402	250.0151	0.527665	250.0151	0.464083	250.0151	0.333322	250.0151	0.232447	250.0151	0.043491	250.0151	0.060543
248.9909	0.612776	248.9909	0.602398	248.9909	0.527668	248.9909	0.464406	248.9909	0.334066	248.9909	0.233656	248.9909	0.04466	248.9909	0.061759
248.006	0.609426	248.006	0.599223	248.006	0.525075	248.006	0.461954	248.006	0.332298	248.006	0.232785	248.006	0.044466	248.006	0.061674
246.9816	0.605581	246.9816	0.595516	246.9816	0.521805	246.9816	0.459201	246.9816	0.330267	246.9816	0.230663	246.9816	0.044108	246.9816	0.061175
245.9965	0.599946	245.9965	0.590001	245.9965	0.516716	245.9965	0.454781	245.9965	0.326607	245.9965	0.227767	245.9965	0.042641	245.9965	0.059812
245.0113	0.593872	245.0113	0.583988	245.0113	0.511778	245.0113	0.450227	245.0113	0.323507	245.0113	0.226613	245.0113	0.042522	245.0113	0.059574

12.5 mg Evoqua 12x40 with 10 ppm DNT solution

E40		E41		E42		E43		E44		E45		E46		E47		E48	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
259.9995	0.574409	259.9995	0.546887	259.9995	0.473145	259.9995	0.427672	259.9995	0.320139	259.9995	0.219265	259.9995	0.150716	259.9995	0.078192	259.9995	0.063216
259.0156	0.582167	259.0156	0.554732	259.0156	0.479849	259.0156	0.434139	259.0156	0.325189	259.0156	0.222934	259.0156	0.153472	259.0156	0.080155	259.0156	0.065292
257.9923	0.59152	257.9923	0.563676	257.9923	0.488007	257.9923	0.441436	257.9923	0.331032	257.9923	0.227299	257.9923	0.156785	257.9923	0.082352	257.9923	0.066987
257.0083	0.598672	257.0083	0.570843	257.0083	0.49435	257.0083	0.447239	257.0083	0.335539	257.0083	0.230546	257.0083	0.159554	257.0083	0.084401	257.0083	0.068587
255.9848	0.605918	255.9848	0.577342	255.9848	0.500277	255.9848	0.452412	255.9848	0.34017	255.9848	0.234181	255.9848	0.161896	255.9848	0.086371	255.9848	0.069944
255.0006	0.611609	255.0006	0.583266	255.0006	0.505285	255.0006	0.4576	255.0006	0.344004	255.0006	0.236617	255.0006	0.164122	255.0006	0.087631	255.0006	0.071164
254.0163	0.616622	254.0163	0.588267	254.0163	0.509626	254.0163	0.460965	254.0163	0.346982	254.0163	0.238806	254.0163	0.165776	254.0163	0.088458	254.0163	0.071627
252.9925	0.621007	252.9925	0.592053	252.9925	0.513543	252.9925	0.464131	252.9925	0.350126	252.9925	0.240614	252.9925	0.167501	252.9925	0.089224	252.9925	0.071953
252.0079	0.622718	252.0079	0.593923	252.0079	0.514576	252.0079	0.465901	252.0079	0.351358	252.0079	0.241718	252.0079	0.168499	252.0079	0.089534	252.0079	0.072722
250.9839	0.624785	250.9839	0.596022	250.9839	0.516354	250.9839	0.467725	250.9839	0.353425	250.9839	0.243126	250.9839	0.170232	250.9839	0.090095	250.9839	0.073307
249.9992	0.625495	249.9992	0.596455	249.9992	0.51753	249.9992	0.46845	249.9992	0.35484	249.9992	0.244076	249.9992	0.1712	249.9992	0.090246	249.9992	0.073166
249.0144	0.626326	249.0144	0.597161	249.0144	0.518327	249.0144	0.469599	249.0144	0.356414	249.0144	0.245509	249.0144	0.173267	249.0144	0.091457	249.0144	0.074331
247.9901	0.623454	247.9901	0.59488	247.9901	0.516689	247.9901	0.467784	247.9901	0.355975	247.9901	0.245003	247.9901	0.173497	247.9901	0.090806	247.9901	0.073711
247.0051	0.619374	247.0051	0.591193	247.0051	0.513198	247.0051	0.465242	247.0051	0.354341	247.0051	0.243775	247.0051	0.17329	247.0051	0.089773	247.0051	0.073428
245.9807	0.614156	245.9807	0.586053	245.9807	0.508993	245.9807	0.461515	245.9807	0.352073	245.9807	0.241842	245.9807	0.17251	245.9807	0.087615	245.9807	0.071695
244.9955	0.609078	244.9955	0.581036	244.9955	0.504579	244.9955	0.457911	244.9955	0.350196	244.9955	0.240646	244.9955	0.172297	244.9955	0.086494	244.9955	0.070501

12.5 mg Modified F600 with 10ppm DNT Solution

F60		F61		F62		F63		F64		F65		F66		F67		F68	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
259.9995	0.611748	259.9995	0.418897	259.9995	0.331118	259.9995	0.258484	259.9995	0.200721	259.9995	0.106929	259.9995	0.099001	259.9995	0.087297	259.9995	0.076753
259.0156	0.619414	259.0156	0.42451	259.0156	0.335728	259.0156	0.262261	259.0156	0.203849	259.0156	0.108529	259.0156	0.100403	259.0156	0.088855	259.0156	0.078043
257.9923	0.628503	257.9923	0.430771	257.9923	0.340839	257.9923	0.266528	257.9923	0.207238	257.9923	0.110651	257.9923	0.102534	257.9923	0.090463	257.9923	0.079436
257.0083	0.636374	257.0083	0.435723	257.0083	0.344986	257.0083	0.270133	257.0083	0.209932	257.0083	0.112281	257.0083	0.104068	257.0083	0.092192	257.0083	0.08112
255.9848	0.642896	255.9848	0.440371	255.9848	0.348648	255.9848	0.273562	255.9848	0.212395	255.9848	0.113745	255.9848	0.105344	255.9848	0.093418	255.9848	0.082125
255.0006	0.648414	255.0006	0.444408	255.0006	0.352045	255.0006	0.276437	255.0006	0.214866	255.0006	0.114998	255.0006	0.106451	255.0006	0.094462	255.0006	0.083194
254.0163	0.652898	254.0163	0.447128	254.0163	0.354179	254.0163	0.278972	254.0163	0.216128	254.0163	0.115444	254.0163	0.107073	254.0163	0.094915	254.0163	0.083661
252.9925	0.656909	252.9925	0.449472	252.9925	0.35615	252.9925	0.281659	252.9925	0.217868	252.9925	0.11622	252.9925	0.107904	252.9925	0.095706	252.9925	0.084403
252.0079	0.658601	252.0079	0.450974	252.0079	0.357079	252.0079	0.284099	252.0079	0.219084	252.0079	0.116609	252.0079	0.108122	252.0079	0.095969	252.0079	0.084585
250.9839	0.659591	250.9839	0.451831	250.9839	0.357856	250.9839	0.286549	250.9839	0.220464	250.9839	0.117171	250.9839	0.108868	250.9839	0.096628	250.9839	0.08527
249.9992	0.660175	249.9992	0.451689	249.9992	0.357924	249.9992	0.288701	249.9992	0.221402	249.9992	0.117321	249.9992	0.109391	249.9992	0.096887	249.9992	0.085665
249.0144	0.660029	249.0144	0.451917	249.0144	0.35858	249.0144	0.2924	249.0144	0.223495	249.0144	0.118576	249.0144	0.110916	249.0144	0.098521	249.0144	0.087222
247.9901	0.656703	247.9901	0.449594	247.9901	0.356571	247.9901	0.294401	247.9901	0.22375	247.9901	0.11827	247.9901	0.110556	247.9901	0.098304	247.9901	0.087146
247.0051	0.652535	247.0051	0.447209	247.0051	0.354325	247.0051	0.296679	247.0051	0.224121	247.0051	0.117593	247.0051	0.110314	247.0051	0.097725	247.0051	0.086823
245.9807	0.646361	245.9807	0.442584	245.9807	0.350288	245.9807	0.297859	245.9807	0.223074	245.9807	0.115752	245.9807	0.108426	245.9807	0.096377	245.9807	0.085212
244.9955	0.639953	244.9955	0.437805	244.9955	0.346802	244.9955	0.299722	244.9955	0.222693	244.9955	0.115072	244.9955	0.108474	244.9955	0.096213	244.9955	0.085217

12.5 mg Modified F600 with 10ppm DNT Solution															
12.5F60		12F61		12F62		12F63		12F64		12F65		12F66		12F67	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
260.0154	0.605725	260.0154	0.429822	260.0154	0.331931	260.0154	0.221315	260.0154	0.154514	260.0154	0.107866	260.0154	0.0621	260.0154	0.008708
258.9921	0.613731	258.9921	0.435868	258.9921	0.336605	258.9921	0.224655	258.9921	0.157165	258.9921	0.1095	258.9921	0.063317	258.9921	0.009045
258.0082	0.622903	258.0082	0.442628	258.0082	0.341959	258.0082	0.228298	258.0082	0.159666	258.0082	0.11156	258.0082	0.064459	258.0082	0.009572
256.9848	0.630107	256.9848	0.447823	256.9848	0.346015	256.9848	0.231294	256.9848	0.161997	256.9848	0.11319	256.9848	0.065876	256.9848	0.010371
256.0007	0.63694	256.0007	0.452727	256.0007	0.350045	256.0007	0.233745	256.0007	0.163786	256.0007	0.114708	256.0007	0.06671	256.0007	0.010593
255.0165	0.642291	255.0165	0.457184	255.0165	0.353183	255.0165	0.236072	255.0165	0.165352	255.0165	0.115854	255.0165	0.067545	255.0165	0.010804
253.9927	0.646702	253.9927	0.459952	253.9927	0.355692	253.9927	0.237817	253.9927	0.16636	253.9927	0.116864	253.9927	0.067606	253.9927	0.010663
253.0083	0.650313	253.0083	0.462804	253.0083	0.357793	253.0083	0.23915	253.0083	0.167361	253.0083	0.117613	253.0083	0.068035	253.0083	0.010657
251.9845	0.652516	251.9845	0.464114	251.9845	0.358766	251.9845	0.239896	251.9845	0.167839	251.9845	0.117612	251.9845	0.06825	251.9845	0.010601
250.9998	0.653693	250.9998	0.465127	250.9998	0.359722	250.9998	0.240697	250.9998	0.168566	250.9998	0.118387	250.9998	0.068774	250.9998	0.010959
250.0151	0.653753	250.0151	0.465282	250.0151	0.359726	250.0151	0.240702	250.0151	0.168816	250.0151	0.118897	250.0151	0.068839	250.0151	0.011046
248.9909	0.653462	248.9909	0.465366	248.9909	0.360193	248.9909	0.241663	248.9909	0.169621	248.9909	0.120479	248.9909	0.070004	248.9909	0.012572
248.006	0.649914	248.006	0.463173	248.006	0.358658	248.006	0.240333	248.006	0.168986	248.006	0.120046	248.006	0.069842	248.006	0.012634
246.9816	0.64618	246.9816	0.460305	246.9816	0.356296	246.9816	0.238867	246.9816	0.168154	246.9816	0.11914	246.9816	0.06931	246.9816	0.012407
245.9965	0.639832	245.9965	0.455701	245.9965	0.352298	245.9965	0.235949	245.9965	0.165897	245.9965	0.117286	245.9965	0.067813	245.9965	0.011282
245.0113	0.63356	245.0113	0.451276	245.0113	0.349126	245.0113	0.233991	245.0113	0.164441	245.0113	0.116925	245.0113	0.067256	245.0113	0.011559

12.5 mg Modified F600 with 10ppm DNT Solution															
3MF60		3MF61		3MF62		3MF63		3MF64		3MF65		3MF66		3MF67	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
260.0008	0.638394	260.0008	0.460541	260.0008	0.38339	260.0008	0.28999	260.0008	0.200344	260.0008	0.140868	260.0008	0.067174	260.0008	0.051566
259.017	0.647021	259.017	0.466519	259.017	0.388643	259.017	0.294578	259.017	0.203616	259.017	0.143112	259.017	0.068237	259.017	0.053262
257.9937	0.656724	257.9937	0.474137	257.9937	0.394588	257.9937	0.29947	257.9937	0.207438	257.9937	0.14615	257.9937	0.070135	257.9937	0.054785
257.0096	0.664385	257.0096	0.479876	257.0096	0.400015	257.0096	0.303792	257.0096	0.210316	257.0096	0.148397	257.0096	0.07148	257.0096	0.056067
255.9861	0.671957	255.9861	0.485877	255.9861	0.40494	255.9861	0.307411	255.9861	0.213066	255.9861	0.150707	255.9861	0.072833	255.9861	0.057274
255.0019	0.678302	255.0019	0.490227	255.0019	0.409073	255.0019	0.310829	255.0019	0.215604	255.0019	0.152446	255.0019	0.073855	255.0019	0.058277
254.0176	0.683633	254.0176	0.494126	254.0176	0.411776	254.0176	0.313171	254.0176	0.217115	254.0176	0.153451	254.0176	0.074415	254.0176	0.058592
252.9938	0.688011	252.9938	0.497138	252.9938	0.414949	252.9938	0.314975	252.9938	0.218815	252.9938	0.154799	252.9938	0.075306	252.9938	0.059128
252.0093	0.689631	252.0093	0.49866	252.0093	0.41599	252.0093	0.316443	252.0093	0.219441	252.0093	0.155083	252.0093	0.075026	252.0093	0.0596
250.9853	0.691235	250.9853	0.499543	250.9853	0.417148	250.9853	0.317341	250.9853	0.220038	250.9853	0.155827	250.9853	0.07572	250.9853	0.060165
250.0005	0.691447	250.0005	0.499876	250.0005	0.417438	250.0005	0.31731	250.0005	0.220586	250.0005	0.156092	250.0005	0.076114	250.0005	0.060251
249.0158	0.691734	249.0158	0.500459	249.0158	0.418055	249.0158	0.318189	249.0158	0.221484	249.0158	0.157321	249.0158	0.077689	249.0158	0.061826
247.9915	0.68861	247.9915	0.497275	247.9915	0.415996	247.9915	0.316869	247.9915	0.220542	247.9915	0.156562	247.9915	0.077395	247.9915	0.061567
247.0065	0.683483	247.0065	0.494399	247.0065	0.413318	247.0065	0.315127	247.0065	0.218845	247.0065	0.155286	247.0065	0.076512	247.0065	0.061265
245.9819	0.677027	245.9819	0.488963	245.9819	0.408743	245.9819	0.311819	245.9819	0.216022	245.9819	0.152691	245.9819	0.074749	245.9819	0.059846
244.9967	0.670448	244.9967	0.483998	244.9967	0.405027	244.9967	0.308386	244.9967	0.213699	244.9967	0.151383	244.9967	0.074578	244.9967	0.059557

12.5 mg of Modified Norit 400 with 10 PPM DNT solution																
N40		N41		N42		N43		N44		N45		N46		N47		
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	
260.0063	0.56858	260.0063	0.48545	260.0063	0.375196	260.0063	0.182215	260.0063	0.061463	260.0063	0.022798	260.0063	0.003415	260.0063	0.006339	
258.9832	0.575766	258.9832	0.491527	258.9832	0.380319	258.9832	0.185009	258.9832	0.062682	258.9832	0.023476	258.9832	0.003906	258.9832	0.00684	
257.9994	0.584675	257.9994	0.49959	257.9994	0.386093	257.9994	0.187946	257.9994	0.06413	257.9994	0.024177	257.9994	0.004378	257.9994	0.007274	
257.0155	0.59157	257.0155	0.505342	257.0155	0.391033	257.0155	0.190426	257.0155	0.065383	257.0155	0.02501	257.0155	0.004973	257.0155	0.008098	
255.9921	0.597663	255.9921	0.510912	255.9921	0.395441	255.9921	0.192869	255.9921	0.066411	255.9921	0.025615	255.9921	0.005352	255.9921	0.008364	
255.008	0.603145	255.008	0.515433	255.008	0.399192	255.008	0.194877	255.008	0.067212	255.008	0.02604	255.008	0.005625	255.008	0.008601	
253.9844	0.607043	253.9844	0.51902	253.9844	0.401963	253.9844	0.195894	253.9844	0.067391	253.9844	0.026032	253.9844	0.005295	253.9844	0.008336	
253.0001	0.610667	253.0001	0.521641	253.0001	0.404387	253.0001	0.197175	253.0001	0.067856	253.0001	0.026215	253.0001	0.005552	253.0001	0.008529	
252.0157	0.612127	252.0157	0.522981	252.0157	0.405396	252.0157	0.197795	252.0157	0.06806	252.0157	0.02606	252.0157	0.005304	252.0157	0.008433	
250.9918	0.613285	250.9918	0.524274	250.9918	0.406346	250.9918	0.19833	250.9918	0.06838	250.9918	0.026629	250.9918	0.005672	250.9918	0.008828	
250.0072	0.613358	250.0072	0.52402	250.0072	0.406595	250.0072	0.198446	250.0072	0.068501	250.0072	0.026623	250.0072	0.005915	250.0072	0.009092	
248.9831	0.612958	248.9831	0.524456	248.9831	0.406893	248.9831	0.199521	248.9831	0.069832	248.9831	0.028161	248.9831	0.007226	248.9831	0.010594	
247.9983	0.609964	247.9983	0.521469	247.9983	0.404634	247.9983	0.198152	247.9983	0.069584	247.9983	0.028117	247.9983	0.007235	247.9983	0.010562	
247.0134	0.605923	247.0134	0.518064	247.0134	0.402273	247.0134	0.196743	247.0134	0.069159	247.0134	0.027973	247.0134	0.006984	247.0134	0.010262	
245.989	0.599584	245.989	0.512574	245.989	0.397888	245.989	0.194222	245.989	0.067721	245.989	0.026694	245.989	0.00566	245.989	0.00919	
245.004	0.593643	245.004	0.50733	245.004	0.39395	245.004	0.192504	245.004	0.067245	245.004	0.026856	245.004	0.006246	245.004	0.009689	

12.5mg Evoqua 12x30 Modified with 10 PPM DNT solution																	
EE30		EE31		EE32		EE33		EE34		EE35		EE36		EE37		EE38	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
260.0063	0.607484	260.0099	0.598295	260.0099	0.565667	260.0099	0.496477	260.0099	0.414285	260.0099	0.315432	260.0099	0.253842	260.0099	0.273511	260.0099	0.247932
258.9832	0.61632	258.9867	0.607261	258.9867	0.573679	258.9867	0.504057	258.9867	0.420506	258.9867	0.32084	258.9867	0.258255	258.9867	0.278638	258.9867	0.25206
257.9994	0.625702	258.0027	0.616829	258.0027	0.582952	258.0027	0.512284	258.0027	0.428068	258.0027	0.326384	258.0027	0.263063	258.0027	0.282984	258.0027	0.25686
257.0155	0.63324	257.0187	0.624607	257.0187	0.590324	257.0187	0.519072	257.0187	0.433328	257.0187	0.330727	257.0187	0.266833	257.0187	0.28703	257.0187	0.260475
255.9921	0.640985	255.9953	0.631833	255.9953	0.597439	255.9953	0.525188	255.9953	0.43864	255.9953	0.335062	255.9953	0.270427	255.9953	0.290857	255.9953	0.264064
255.008	0.64707	255.011	0.637968	255.011	0.603195	255.011	0.530423	255.011	0.44326	255.011	0.338756	255.011	0.273825	255.011	0.29398	255.011	0.266936
253.9844	0.652591	253.9873	0.643718	253.9873	0.608265	253.9873	0.534974	253.9873	0.447111	253.9873	0.341641	253.9873	0.276755	253.9873	0.296715	253.9873	0.269821
253.0001	0.656385	253.0029	0.647576	253.0029	0.612376	253.0029	0.538718	253.0029	0.450443	253.0029	0.344239	253.0029	0.278882	253.0029	0.299365	253.0029	0.271877
252.0157	0.658429	252.0184	0.649353	252.0184	0.614068	252.0184	0.540324	252.0184	0.451733	252.0184	0.345335	252.0184	0.279837	252.0184	0.300716	252.0184	0.272894
250.9918	0.660475	250.9944	0.651296	250.9944	0.616321	250.9944	0.542552	250.9944	0.453348	250.9944	0.347277	250.9944	0.281461	250.9944	0.302603	250.9944	0.274189
250.0072	0.661079	250.0097	0.652085	250.0097	0.617028	250.0097	0.542999	250.0097	0.454319	250.0097	0.348002	250.0097	0.282473	250.0097	0.303517	250.0097	0.275187
248.9831	0.66117	248.9855	0.652672	248.9855	0.617819	248.9855	0.543887	248.9855	0.455179	248.9855	0.349024	248.9855	0.284192	248.9855	0.305543	248.9855	0.276814
247.9983	0.65836	248.0006	0.649993	248.0006	0.615144	248.0006	0.5421	248.0006	0.453536	248.0006	0.348001	248.0006	0.283859	248.0006	0.304991	248.0006	0.276297
247.0134	0.654432	247.0156	0.645981	247.0156	0.611719	247.0156	0.538695	247.0156	0.450873	247.0156	0.346036	247.0156	0.2821	247.0156	0.304056	247.0156	0.27475
245.989	0.648981	245.9911	0.640288	245.9911	0.606313	245.9911	0.53381	245.9911	0.447241	245.9911	0.342849	245.9911	0.279393	245.9911	0.302194	245.9911	0.272401
245.004	0.642981	245.0059	0.635409	245.0059	0.601344	245.0059	0.529621	245.0059	0.443459	245.0059	0.340604	245.0059	0.278149	245.0059	0.301034	245.0059	0.270884

12.5 mg Modified Evoqua 12x40 with 10 ppm DNT solution															
E40		E41		E42		E43		E44		E45		E46		E47	
Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs	Wavelen	Abs
260.0063	0.569688	260.0063	0.556574	260.0063	0.449276	260.0063	0.293325	260.0063	0.119671	260.0063	0.071755	260.0063	0.027935	260.0063	0.009518
258.9832	0.577056	258.9832	0.563046	258.9832	0.455063	258.9832	0.297494	258.9832	0.121625	258.9832	0.07317	258.9832	0.028699	258.9832	0.010119
257.9994	0.586262	257.9994	0.571847	257.9994	0.462244	257.9994	0.30226	257.9994	0.12381	257.9994	0.0746	257.9994	0.029457	257.9994	0.010564
257.0155	0.592673	257.0155	0.578492	257.0155	0.467839	257.0155	0.305894	257.0155	0.125767	257.0155	0.076099	257.0155	0.030398	257.0155	0.011414
255.9921	0.599109	255.9921	0.584972	255.9921	0.47317	255.9921	0.309341	255.9921	0.127425	255.9921	0.077129	255.9921	0.031002	255.9921	0.011707
255.008	0.604583	255.008	0.590115	255.008	0.477168	255.008	0.312319	255.008	0.128567	255.008	0.077937	255.008	0.031686	255.008	0.012202
253.9844	0.608713	253.9844	0.594163	253.9844	0.480623	253.9844	0.314086	253.9844	0.129283	253.9844	0.078258	253.9844	0.031424	253.9844	0.011756
253.0001	0.612312	253.0001	0.597775	253.0001	0.48386	253.0001	0.315896	253.0001	0.129985	253.0001	0.078846	253.0001	0.031618	253.0001	0.01218
252.0157	0.613852	252.0157	0.598731	252.0157	0.485034	252.0157	0.316868	252.0157	0.130448	252.0157	0.079016	252.0157	0.03177	252.0157	0.012137
250.9918	0.61503	250.9918	0.599981	250.9918	0.485683	250.9918	0.317827	250.9918	0.130804	250.9918	0.079449	250.9918	0.032152	250.9918	0.01232
250.0072	0.615262	250.0072	0.600115	250.0072	0.486056	250.0072	0.317628	250.0072	0.131018	250.0072	0.079701	250.0072	0.032282	250.0072	0.012546
248.9831	0.614895	248.9831	0.600532	248.9831	0.486134	248.9831	0.318385	248.9831	0.132047	248.9831	0.080911	248.9831	0.033681	248.9831	0.014102
247.9983	0.611989	247.9983	0.597178	247.9983	0.483742	247.9983	0.316502	247.9983	0.131533	247.9983	0.080408	247.9983	0.033464	247.9983	0.014059
247.0134	0.60794	247.0134	0.592808	247.0134	0.480592	247.0134	0.314791	247.0134	0.130668	247.0134	0.080023	247.0134	0.033132	247.0134	0.013719
245.989	0.601949	245.989	0.586259	245.989	0.475585	245.989	0.311234	245.989	0.12863	245.989	0.078378	245.989	0.031758	245.989	0.012676
245.004	0.595827	245.004	0.58133	245.004	0.469628	245.004	0.308052	245.004	0.127557	245.004	0.077967	245.004	0.031873	245.004	0.012912

Appendix B: UV-Vis BB and MB Dye adsorption data

5 PPM BB Dye- 18 mg Modified Evoqua 12x30 day 1													
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
643.982849	0.52148658	643.982849	0.50775933	643.982849	0.48184103	643.982849	0.49893901	643.990601	0.48855272	643.990601	0.50892425	644.01178	0.48064229
642.010498	0.5831092	642.010498	0.56778926	642.010498	0.54211771	642.010498	0.55701619	642.017822	0.54522485	642.017822	0.56623149	642.002869	0.53573418
640.000427	0.64184564	640.000427	0.62208396	640.000427	0.59111083	640.000427	0.61035866	640.007507	0.59649181	640.007507	0.62067628	639.992737	0.58838707
637.989136	0.69270235	637.989136	0.67240614	637.989136	0.64220309	637.989136	0.66201139	637.995911	0.64560848	637.995911	0.66975683	638.018066	0.63812196
636.013428	0.74116635	636.013428	0.71969807	636.013428	0.68111283	636.013428	0.70673996	635.983154	0.68324566	635.983154	0.71465677	636.005676	0.67737406
633.999939	0.76748854	633.999939	0.74868602	633.999939	0.71331388	633.999939	0.73493898	634.005859	0.71322846	634.005859	0.74465603	633.992127	0.70495546
631.985169	0.79480362	631.985169	0.77376747	631.985169	0.73411965	631.985169	0.75588179	631.990906	0.72897339	631.990906	0.76569414	632.013977	0.72115934
630.006104	0.8023091	630.006104	0.77956033	630.006104	0.74122149	630.006104	0.76660943	630.011353	0.73872882	630.011353	0.76949716	629.998169	0.7335791
627.989136	0.80171818	627.989136	0.78320926	627.989136	0.73984283	627.989136	0.76376492	627.994019	0.7353037	627.994019	0.76617771	628.017883	0.72739059
626.00769	0.79078311	626.00769	0.76820546	626.00769	0.72553009	626.00769	0.75487781	626.012329	0.72422367	626.012329	0.75747216	625.999756	0.71625471
623.988464	0.76570231	623.988464	0.74476027	623.988464	0.7058202	623.988464	0.72900587	623.992737	0.69863355	623.992737	0.73235112	624.017212	0.694067
622.004883	0.73466522	622.004883	0.71233904	622.004883	0.67559415	622.004883	0.69781518	622.008789	0.67037827	622.008789	0.69912773	621.996826	0.66573161
619.98346	0.69837856	619.98346	0.67736262	619.98346	0.64251262	619.98346	0.66313636	619.986939	0.636926	619.986939	0.66262841	620.012085	0.63264608
617.99762	0.6577372	617.99762	0.63592279	617.99762	0.60032916	617.99762	0.62145549	618.000794	0.59648097	618.000794	0.62057161	617.989502	0.59460473
616.010803	0.61244637	616.010803	0.59343141	616.010803	0.5628581	616.010803	0.58093405	616.01355	0.56241989	616.01355	0.58156794	616.002502	0.55502886

5 PPM BB Dye- 12.5 mg Modified Evoqua 12x30 day 1													
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
643.982849	0.5112747	643.982849	0.49838835	643.982849	0.49233073	643.982849	0.47614497	643.990601	0.50773281	643.990601	0.50268692	644.01178	0.48069689
642.010498	0.57107449	642.010498	0.55423826	642.010498	0.55300158	642.010498	0.53539437	642.017822	0.56811857	642.017822	0.56201798	642.002869	0.53292006
640.000427	0.62877595	640.000427	0.61725569	640.000427	0.60773319	640.000427	0.58565956	640.007507	0.62074018	640.007507	0.61312574	639.992737	0.58704704
637.989136	0.67868072	637.989136	0.66585392	637.989136	0.65740204	637.989136	0.63617265	637.995911	0.66943026	637.995911	0.66443366	638.018066	0.63569039
636.013428	0.72558928	636.013428	0.70305967	636.013428	0.69714278	636.013428	0.67611438	635.983154	0.70953697	635.983154	0.70523292	636.005676	0.67327863
633.999939	0.75405043	633.999939	0.73443335	633.999939	0.72879624	633.999939	0.70500374	634.005859	0.73969346	634.005859	0.73278487	633.992127	0.70285672
631.985169	0.77431464	631.985169	0.76020622	631.985169	0.74870759	631.985169	0.73124307	631.990906	0.75713766	631.990906	0.75768995	632.013977	0.72200906
630.006104	0.7865324	630.006104	0.76769757	630.006104	0.75890952	630.006104	0.73873526	630.011353	0.76617014	630.011353	0.76425785	629.998169	0.72799611
627.989136	0.78482777	627.989136	0.76320356	627.989136	0.7568841	627.989136	0.7351222	627.994019	0.76221812	627.994019	0.75922006	628.017883	0.72766906
626.00769	0.7723065	626.00769	0.75434262	626.00769	0.74232	626.00769	0.72351676	626.012329	0.75259817	626.012329	0.74901468	625.999756	0.71574569
623.988464	0.75029039	623.988464	0.72779411	623.988464	0.72415763	623.988464	0.69986945	623.992737	0.73053432	623.992737	0.72441733	624.017212	0.69486332
622.004883	0.71907872	622.004883	0.69632143	622.004883	0.6919108	622.004883	0.67033869	622.008789	0.70108205	622.008789	0.68983644	621.996826	0.66499627
619.98346	0.68265104	619.98346	0.66288835	619.98346	0.65673602	619.98346	0.63662124	619.986939	0.66501218	619.986939	0.65590841	620.012085	0.63491452
617.99762	0.64182651	617.99762	0.6213457	617.99762	0.61511058	617.99762	0.59772193	618.000794	0.62380731	618.000794	0.61600953	617.989502	0.59433156
616.010803	0.60146159	616.010803	0.5829199	616.010803	0.57665235	616.010803	0.55696779	616.01355	0.58342874	616.01355	0.57630491	616.002502	0.55667454

5 PPM BB Dye- 6 mg Modified Evoqua 12x30 day 1												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
643.982849	0.50338912	643.982849	0.50886434	643.982849	0.47537479	643.982849	0.50434083	643.990601	0.48945534	643.990601	0.51544428	644.01178	0.50825125
642.010498	0.56343257	642.010498	0.56994188	642.010498	0.53270322	642.010498	0.56128609	642.017822	0.54355735	642.017822	0.57150042	642.002869	0.5688982
640.000427	0.61889011	640.000427	0.62880951	640.000427	0.58858377	640.000427	0.61851203	640.007507	0.59667403	640.007507	0.62728894	639.992737	0.62367111
637.989136	0.66704357	637.989136	0.67871302	637.989136	0.63553542	637.989136	0.67320824	637.995911	0.64407521	637.995911	0.68080723	638.018066	0.67571253
636.013428	0.7117638	636.013428	0.72202659	636.013428	0.67842531	636.013428	0.71844453	635.983154	0.68779874	635.983154	0.72310454	636.005676	0.71690828
633.999939	0.74204344	633.999939	0.75359231	633.999939	0.70778644	633.999939	0.74720299	634.005859	0.71303952	634.005859	0.75169247	633.992127	0.746997
631.985169	0.76316768	631.985169	0.77610725	631.985169	0.72960275	631.985169	0.77157432	631.990906	0.73255402	631.990906	0.77540326	632.013977	0.76760101
630.006104	0.77483118	630.006104	0.78596252	630.006104	0.73755723	630.006104	0.77976048	630.011353	0.74014449	630.011353	0.78249335	629.998169	0.77405447
627.989136	0.77469188	627.989136	0.78352946	627.989136	0.73534471	627.989136	0.77610487	627.994019	0.73552877	627.994019	0.77878755	628.017883	0.77604377
626.00769	0.76115853	626.00769	0.7712388	626.00769	0.72214425	626.00769	0.76402617	626.012329	0.72471392	626.012329	0.76447266	625.999756	0.76087588
623.988464	0.74072963	623.988464	0.75006074	623.988464	0.69839436	623.988464	0.74164802	623.992737	0.70542222	623.992737	0.74239969	624.017212	0.74046379
622.004883	0.70735633	622.004883	0.7165575	622.004883	0.66956323	622.004883	0.70888394	622.008789	0.67326641	622.008789	0.70999652	621.996826	0.71094596
619.98346	0.67378074	619.98346	0.68380445	619.98346	0.63501453	619.98346	0.67239302	619.986939	0.63733232	619.986939	0.672342	620.012085	0.67343229
617.99762	0.63122487	617.99762	0.64284313	617.99762	0.59649509	617.99762	0.62888378	618.000794	0.59959924	618.000794	0.63130379	617.989502	0.63127869
616.010803	0.59094357	616.010803	0.59740651	616.010803	0.55452329	616.010803	0.5860098	616.01355	0.56295431	616.01355	0.58907872	616.002502	0.59210223

5 PPM MB Dye- 18 mg Evoqua 12x30 day 1												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
674.009827	0.80036497	674.009827	0.68320715	674.009827	0.58507645	674.009827	0.44559854	673.986816	0.31423441	673.986816	0.13384263	674.00293	0.00565597
671.982788	0.87199992	671.982788	0.74111539	671.982788	0.64035583	671.982788	0.48707116	671.995544	0.33718663	671.995544	0.14635488	672.012024	0.00505255
669.990601	0.92953455	669.990601	0.78711033	669.990601	0.68221587	669.990601	0.51584864	670.003052	0.35720617	670.003052	0.15442397	669.983582	0.00543702
667.997253	0.95758194	667.997253	0.82029355	667.997253	0.70496356	667.997253	0.53544933	668.009216	0.37201136	668.009216	0.15933941	667.990112	0.00572385
666.002625	0.97464377	666.002625	0.8337127	666.002625	0.71975577	666.002625	0.54588109	666.014282	0.37792006	666.014282	0.16255876	665.995544	0.00507895
664.006836	0.98549491	664.006836	0.84161341	664.006836	0.72139883	664.006836	0.54983896	664.018127	0.38054907	664.018127	0.16176549	663.999695	0.00493529
662.009827	0.97841412	662.009827	0.83280647	662.009827	0.72090894	662.009827	0.54442644	661.984436	0.3752389	661.984436	0.16184825	662.002625	0.00514451
660.011536	0.95994478	660.011536	0.82096708	660.011536	0.70640641	660.011536	0.534594	659.98584	0.36905375	659.98584	0.15920872	660.004334	0.00547366
658.012207	0.94343829	658.012207	0.79929024	658.012207	0.69096369	658.012207	0.52086937	657.986084	0.36272126	657.986084	0.1554828	658.004883	0.00397196
656.011597	0.91119391	656.011597	0.7812596	656.011597	0.66845059	656.011597	0.50771701	655.985046	0.35185423	655.985046	0.15032429	656.00415	0.00467246
654.009705	0.89005822	654.009705	0.75781161	654.009705	0.65061831	654.009705	0.49171928	653.982849	0.33941799	653.982849	0.14547116	654.002319	0.0048193

5 PPM MB Dye- 12.5 mg Evoqua 12x30 day 1

Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
674.009827	0.81593484	674.009827	0.73112518	674.009827	0.61968982	674.009827	0.52923483	673.986816	0.39299658	673.986816	0.22656557	674.00293	0.00611166
671.982788	0.88009399	671.982788	0.79587686	671.982788	0.67484897	671.982788	0.57619101	671.995544	0.42367944	671.995544	0.24579117	672.012024	0.00730792
669.990601	0.93591052	669.990601	0.84650558	669.990601	0.71761656	669.990601	0.61132002	670.003052	0.44946253	670.003052	0.26005116	669.983582	0.00716944
667.997253	0.97148007	667.997253	0.87474799	667.997253	0.74541098	667.997253	0.63415343	668.009216	0.46437654	668.009216	0.26905519	667.990112	0.00632815
666.002625	0.99720716	666.002625	0.89331305	666.002625	0.76061004	666.002625	0.6532768	666.014282	0.47523949	666.014282	0.27390152	665.995544	0.00700857
664.006836	1.00018847	664.006836	0.89985681	664.006836	0.76429856	664.006836	0.65501302	664.018127	0.47481015	664.018127	0.27589837	663.999695	0.00694957
662.009827	0.99735713	662.009827	0.89748228	662.009827	0.75913674	662.009827	0.6490224	661.984436	0.47122705	661.984436	0.27282625	662.002625	0.00704593
660.011536	0.98015398	660.011536	0.87799585	660.011536	0.74635875	660.011536	0.63571858	659.98584	0.46256733	659.98584	0.26815602	660.004334	0.00741047
658.012207	0.95424831	658.012207	0.86095363	658.012207	0.73207968	658.012207	0.61922902	657.986084	0.45232752	657.986084	0.2634851	658.004883	0.00752597
656.011597	0.93311191	656.011597	0.83896327	656.011597	0.70889747	656.011597	0.60349089	655.985046	0.44080657	655.985046	0.2547453	656.00415	0.00800402
654.009705	0.90607172	654.009705	0.81469232	654.009705	0.69115919	654.009705	0.58726066	653.982849	0.42514819	653.982849	0.24773449	654.002319	0.00753551

5 PPM MB Dye- 6 mg Evoqua 12x30 day 1

Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
674.009827	0.80132014	674.009827	0.74094599	674.009827	0.71778625	674.009827	0.68143797	673.986816	0.63637728	673.986816	0.55198568	674.00293	0.34868428
671.982788	0.86911368	671.982788	0.80203879	671.982788	0.78160763	671.982788	0.7330814	671.995544	0.68995363	671.995544	0.59967291	672.012024	0.3792904
669.990601	0.92183781	669.990601	0.86387867	669.990601	0.82881683	669.990601	0.78474337	670.003052	0.72534299	670.003052	0.63518244	669.983582	0.40302846
667.997253	0.9637683	667.997253	0.89404297	667.997253	0.86391467	667.997253	0.81302428	668.009216	0.75019938	668.009216	0.65808803	667.990112	0.41727772
666.002625	0.97359473	666.002625	0.91219163	666.002625	0.87455809	666.002625	0.8266021	666.014282	0.76604915	666.014282	0.66709781	665.995544	0.42611158
664.006836	0.98214167	664.006836	0.91499281	664.006836	0.88280344	664.006836	0.83095324	664.018127	0.76800972	664.018127	0.67075747	663.999695	0.42640388
662.009827	0.97380722	662.009827	0.91735041	662.009827	0.874816	662.009827	0.82424587	661.984436	0.7649138	661.984436	0.66674703	662.002625	0.42656899
660.011536	0.96246696	660.011536	0.89295602	660.011536	0.85802221	660.011536	0.81160426	659.98584	0.75056481	659.98584	0.65257025	660.004334	0.41854426
658.012207	0.94228017	658.012207	0.88079453	658.012207	0.84741986	658.012207	0.79543477	657.986084	0.73277909	657.986084	0.6398828	658.004883	0.41174108
656.011597	0.92331505	656.011597	0.85565525	656.011597	0.82284987	656.011597	0.7721535	655.985046	0.71253473	655.985046	0.62140554	656.00415	0.40098983
654.009705	0.88905555	654.009705	0.82654095	654.009705	0.79345882	654.009705	0.75246888	653.982849	0.69281709	653.982849	0.59928513	654.002319	0.38832563

5 PPM MB Dye- 18 mg Modified Evoqua 12x30 day 1

Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
674.009827	0.78081793	674.009827	0.72808307	674.009827	0.64099008	674.009827	0.53524905	673.986816	0.43153179	673.986816	0.27256444	674.00293	0.00178571
671.982788	0.84082079	671.982788	0.79362214	671.982788	0.70067334	671.982788	0.58445901	671.995544	0.46683544	671.995544	0.29441077	672.012024	0.00170644
669.990601	0.89998776	669.990601	0.84148294	669.990601	0.74514616	669.990601	0.62282097	670.003052	0.49355787	670.003052	0.31257796	669.983582	0.0004939
667.997253	0.93857259	667.997253	0.87431926	667.997253	0.77119982	667.997253	0.64724493	668.009216	0.51189864	668.009216	0.32103574	667.990112	0.00058096
666.002625	0.9459936	666.002625	0.89003044	666.002625	0.78751248	666.002625	0.6590243	666.014282	0.52218461	666.014282	0.32730076	665.995544	-0.0001292
664.006836	0.95449758	664.006836	0.89890248	664.006836	0.79541045	664.006836	0.66189593	664.018127	0.5230782	664.018127	0.33034843	663.999695	-0.0007451
662.009827	0.95226198	662.009827	0.89481562	662.009827	0.78338718	662.009827	0.65791541	661.984436	0.51846403	661.984436	0.32686895	662.002625	0.00049051
660.011536	0.93585616	660.011536	0.87616134	660.011536	0.77172512	660.011536	0.64598489	659.98584	0.50916696	659.98584	0.32085991	660.004334	9.45E-06
658.012207	0.91409487	658.012207	0.85915262	658.012207	0.75584185	658.012207	0.63167	657.986084	0.49921373	657.986084	0.31430086	658.004883	0.00075946
656.011597	0.88973284	656.011597	0.83025759	656.011597	0.73690993	656.011597	0.61476713	655.985046	0.48534557	655.985046	0.30440351	656.00415	0.00081778
654.009705	0.8669731	654.009705	0.80549526	654.009705	0.71574426	654.009705	0.59557658	653.982849	0.4718897	653.982849	0.29416975	654.002319	0.00018114

5 PPM MB Dye- 12.5 mg Modified Evoqua 12x30 day 1												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
674.009827	0.78725213	674.009827	0.73923767	674.009827	0.69963539	674.009827	0.59769166	673.986816	0.5512073	673.986816	0.48012725	674.00293	0.27346131
671.982788	0.85862803	671.982788	0.79989988	671.982788	0.75605804	671.982788	0.65626454	671.995544	0.59397197	671.995544	0.51990461	672.012024	0.29692289
669.990601	0.91043705	669.990601	0.84934354	669.990601	0.80672753	669.990601	0.69619501	670.003052	0.63094044	670.003052	0.54980433	669.983582	0.31518734
667.997253	0.94515872	667.997253	0.8833347	667.997253	0.83412528	667.997253	0.72294742	668.009216	0.65141255	668.009216	0.56961697	667.990112	0.32627907
666.002625	0.96829504	666.002625	0.90265137	666.002625	0.84941721	666.002625	0.73960108	666.014282	0.6627717	666.014282	0.58024174	665.995544	0.33199936
664.006836	0.97096443	664.006836	0.91072375	664.006836	0.85490638	664.006836	0.74459183	664.018127	0.66666669	664.018127	0.58371085	663.999695	0.33335498
662.009827	0.96104157	662.009827	0.89838654	662.009827	0.84803081	662.009827	0.735331	661.984436	0.66097015	661.984436	0.57653415	662.002625	0.3312048
660.011536	0.94834155	660.011536	0.88505811	660.011536	0.83557802	660.011536	0.72285914	659.98584	0.65102839	659.98584	0.56767643	660.004334	0.32699847
658.012207	0.92528969	658.012207	0.86559147	658.012207	0.81659043	658.012207	0.70858961	657.986084	0.63418788	657.986084	0.55364323	658.004883	0.31984064
656.011597	0.90489358	656.011597	0.84342945	656.011597	0.7922098	656.011597	0.68523395	655.985046	0.61896527	655.985046	0.54003054	656.00415	0.30982536
654.009705	0.87583017	654.009705	0.81675559	654.009705	0.77463865	654.009705	0.66860974	653.982849	0.60258633	653.982849	0.52174199	654.002319	0.30091321

5 PPM MB Dye- 6 mg Modified Evoqua 12x30 day 1												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
674.009827	0.81231594	674.009827	0.77546334	674.009827	0.75663191	674.009827	0.66654152	673.986816	0.63563007	673.986816	0.54426384	674.00293	0.31090465
671.982788	0.88059497	671.982788	0.8347652	671.982788	0.82571107	671.982788	0.71977109	671.995544	0.68374759	671.995544	0.5848226	672.012024	0.3371492
669.990601	0.93403846	669.990601	0.89314079	669.990601	0.86966538	669.990601	0.76568735	670.003052	0.72419232	670.003052	0.62607765	669.983582	0.35737622
667.997253	0.9683339	667.997253	0.92244524	667.997253	0.90501231	667.997253	0.79361647	668.009216	0.75040132	668.009216	0.64671606	667.990112	0.37009725
666.002625	0.99289715	666.002625	0.94142121	666.002625	0.92522979	666.002625	0.81030834	666.014282	0.76694477	666.014282	0.65592563	665.995544	0.37778777
664.006836	0.9916743	664.006836	0.9471941	664.006836	0.9273544	664.006836	0.81403238	664.018127	0.76670796	664.018127	0.66041827	663.999695	0.37853122
662.009827	0.98819035	662.009827	0.94456846	662.009827	0.92754644	662.009827	0.81013316	661.984436	0.76152116	661.984436	0.65146959	662.002625	0.37753448
660.011536	0.97484607	660.011536	0.92507267	660.011536	0.90769327	660.011536	0.79617441	659.98584	0.74896812	659.98584	0.6400159	660.004334	0.37025151
658.012207	0.95159858	658.012207	0.90469009	658.012207	0.88941813	658.012207	0.77569306	657.986084	0.73141229	657.986084	0.62765282	658.004883	0.36209971
656.011597	0.92639536	656.011597	0.87595934	656.011597	0.86135185	656.011597	0.75744784	655.985046	0.71191847	655.985046	0.61005235	656.00415	0.35283417
654.009705	0.90166116	654.009705	0.85844237	654.009705	0.8405847	654.009705	0.73385334	653.982849	0.69351894	653.982849	0.59014499	654.002319	0.34254551

5 PPM BB Dye- 18 mg Modified Evoqua 12x30 day 3												
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
636.98291	0.71115351	636.98291	0.70762926	636.98291	0.68964338	636.98291	0.69497889	636.98291	0.70020211	636.98291	0.67133063	636.98291	0.65146685
635.992737	0.73216957	635.992737	0.72690314	635.992737	0.70815647	635.992737	0.71895361	635.992737	0.72108907	635.992737	0.68878281	635.992737	0.67080855
635.002441	0.75189781	635.002441	0.74677569	635.002441	0.72728884	635.002441	0.73290581	635.002441	0.73880416	635.002441	0.70892513	635.002441	0.68787217
634.011719	0.76321441	634.011719	0.7599625	634.011719	0.73941326	634.011719	0.74807608	634.011719	0.75290358	634.011719	0.72413915	634.011719	0.70237368
632.98407	0.77743393	632.98407	0.7731908	632.98407	0.75428385	632.98407	0.76180261	632.98407	0.76412088	632.98407	0.73437607	632.98407	0.71198499
631.992859	0.78988725	631.992859	0.78341389	631.992859	0.76499426	631.992859	0.77049166	631.992859	0.77527648	631.992859	0.74325645	631.992859	0.72162962
631.001343	0.79342163	631.001343	0.78808576	631.001343	0.77256805	631.001343	0.77478355	631.001343	0.78195912	631.001343	0.74960065	631.001343	0.72706777
630.009522	0.79791945	630.009522	0.78995889	630.009522	0.7719518	630.009522	0.77737588	630.009522	0.78566396	630.009522	0.75128555	630.009522	0.72960335
629.017456	0.79748374	629.017456	0.79420328	629.017456	0.77270657	629.017456	0.77879697	629.017456	0.78491825	629.017456	0.75031686	629.017456	0.72938597
627.988281	0.79454428	627.988281	0.79135549	627.988281	0.77045333	627.988281	0.7768212	627.988281	0.78111661	627.988281	0.75077695	627.988281	0.72560149
626.995728	0.79212827	626.995728	0.78395802	626.995728	0.76624727	626.995728	0.77104467	626.995728	0.77562213	626.995728	0.74437016	626.995728	0.71983212
626.002808	0.78074706	626.002808	0.775307	626.002808	0.75493866	626.002808	0.76045883	626.002808	0.76653665	626.002808	0.73432112	626.002808	0.71232688
625.009583	0.77036482	625.009583	0.76762587	625.009583	0.74696136	625.009583	0.75285298	625.009583	0.75597245	625.009583	0.72775316	625.009583	0.70232117
624.016113	0.75796259	624.016113	0.75272679	624.016113	0.73292834	624.016113	0.74113315	624.016113	0.74322063	624.016113	0.71134853	624.016113	0.69114912
5 PPM BB Dye- 12.5 mg Modified Evoqua 12x30 day 3												
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
636.98291	0.717704	636.98291	0.71880543	636.98291	0.70978034	636.98291	0.71138793	636.98291	0.7126478	636.98291	0.71053523	636.98291	0.66002083
635.992737	0.74019134	635.992737	0.74012125	635.992737	0.72828913	635.992737	0.73505384	635.992737	0.73407513	635.992737	0.73295951	635.992737	0.67774171
635.002441	0.75597429	635.002441	0.75739962	635.002441	0.74841362	635.002441	0.75279439	635.002441	0.75431645	635.002441	0.75023907	635.002441	0.69829029
634.011719	0.77127141	634.011719	0.77238154	634.011719	0.76302564	634.011719	0.76920456	634.011719	0.76573455	634.011719	0.76511854	634.011719	0.70936346
632.98407	0.78529483	632.98407	0.7845344	632.98407	0.77575207	632.98407	0.78272444	632.98407	0.78060657	632.98407	0.77850473	632.98407	0.72220516
631.992859	0.79636604	631.992859	0.79333544	631.992859	0.78683734	631.992859	0.79300147	631.992859	0.79101896	631.992859	0.78937239	631.992859	0.73061705
631.001343	0.80121362	631.001343	0.80181772	631.001343	0.79212207	631.001343	0.7978695	631.001343	0.80003494	631.001343	0.79249984	631.001343	0.73587984
630.009522	0.80591822	630.009522	0.80309141	630.009522	0.79474473	630.009522	0.79927582	630.009522	0.80000281	630.009522	0.79634357	630.009522	0.73789436
629.017456	0.80431354	629.017456	0.80536979	629.017456	0.79540926	629.017456	0.79814506	629.017456	0.79946464	629.017456	0.79680342	629.017456	0.7398144
627.988281	0.80005556	627.988281	0.80144721	627.988281	0.79367769	627.988281	0.79786235	627.988281	0.79876024	627.988281	0.79396433	627.988281	0.73675776
626.995728	0.79601222	626.995728	0.79605353	626.995728	0.78681576	626.995728	0.79220343	626.995728	0.79054087	626.995728	0.78748995	626.995728	0.73258048
626.002808	0.78651583	626.002808	0.78826588	626.002808	0.77925015	626.002808	0.78296357	626.002808	0.7800855	626.002808	0.77706629	626.002808	0.72143215
625.009583	0.77601695	625.009583	0.77984071	625.009583	0.76715905	625.009583	0.77580285	625.009583	0.77166444	625.009583	0.76922661	625.009583	0.71264243
624.016113	0.7662887	624.016113	0.76439303	624.016113	0.75236136	624.016113	0.75992429	624.016113	0.75724864	624.016113	0.7548849	624.016113	0.70178521

5 PPM BB Dye- 6 mg Modified Evoqua 12x30 day 3														
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	
636.98291	0.72612488	636.98291	0.7154274	636.98291	0.71194315	636.98291	0.67982501	636.98291	0.73107219	636.98291	0.72872955	636.98291	0.71135789	
635.992737	0.74521101	635.992737	0.73793453	635.992737	0.73030937	635.992737	0.70067626	635.992737	0.74967325	635.992737	0.75052995	635.992737	0.72954613	
635.002441	0.76241952	635.002441	0.75682378	635.002441	0.74852574	635.002441	0.71737593	635.002441	0.76930696	635.002441	0.77157837	635.002441	0.74768293	
634.011719	0.77873081	634.011719	0.76907575	634.011719	0.76433867	634.011719	0.73233914	634.011719	0.78725535	634.011719	0.78418016	634.011719	0.7641173	
632.98407	0.7871542	632.98407	0.78448719	632.98407	0.77636963	632.98407	0.74552012	632.98407	0.80167592	632.98407	0.7961905	632.98407	0.77566749	
631.992859	0.79765844	631.992859	0.79431564	631.992859	0.78787541	631.992859	0.75222045	631.992859	0.81043035	631.992859	0.8072719	631.992859	0.78733367	
631.001343	0.80350012	631.001343	0.79680526	631.001343	0.79081309	631.001343	0.7579298	631.001343	0.81456965	631.001343	0.8161546	631.001343	0.79064131	
630.009522	0.80892086	630.009522	0.8014679	630.009522	0.79617745	630.009522	0.7629965	630.009522	0.81987321	630.009522	0.81918806	630.009522	0.7965259	
629.017456	0.80982465	629.017456	0.80309653	629.017456	0.79584462	629.017456	0.764328	629.017456	0.81987584	629.017456	0.81988722	629.017456	0.79721522	
627.988281	0.8053776	627.988281	0.79983795	627.988281	0.79320175	627.988281	0.76082313	627.988281	0.81501287	627.988281	0.81437397	627.988281	0.79641306	
626.995728	0.79925942	626.995728	0.79510939	626.995728	0.78601301	626.995728	0.75520992	626.995728	0.8106674	626.995728	0.8072508	626.995728	0.79025567	
626.002808	0.79039913	626.002808	0.78453851	626.002808	0.77666068	626.002808	0.74518824	626.002808	0.80014688	626.002808	0.79908162	626.002808	0.78049815	
625.009583	0.78155208	625.009583	0.77267039	625.009583	0.76637781	625.009583	0.73873937	625.009583	0.78924328	625.009583	0.79005224	625.009583	0.7689454	
624.016113	0.76646954	624.016113	0.75879663	624.016113	0.75652516	624.016113	0.72277033	624.016113	0.77580541	624.016113	0.77634782	624.016113	0.75639272	

5 PPM BB Dye- 18 mg Evoqua 12x30 day 3														
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	
636.98291	0.71731699	636.98291	0.69482338	636.98291	0.7025559	636.98291	0.69089758	636.98291	0.69494808	636.98291	0.6787793	636.98291	0.6234473	
635.992737	0.73672408	635.992737	0.71481431	635.992737	0.72524995	635.992737	0.71170062	635.992737	0.71215093	635.992737	0.69764739	635.992737	0.64115745	
635.002441	0.75803185	635.002441	0.73486126	635.002441	0.74154615	635.002441	0.7309804	635.002441	0.73272258	635.002441	0.71538258	635.002441	0.65924162	
634.011719	0.76953036	634.011719	0.74901623	634.011719	0.75133705	634.011719	0.74444914	634.011719	0.74725545	634.011719	0.729509	634.011719	0.67107642	
632.98407	0.78206462	632.98407	0.76023316	632.98407	0.76715773	632.98407	0.75624138	632.98407	0.75748307	632.98407	0.73833269	632.98407	0.68230993	
631.992859	0.79282296	631.992859	0.7710039	631.992859	0.77739537	631.992859	0.76547629	631.992859	0.76825798	631.992859	0.7512145	631.992859	0.68968517	
631.001343	0.79795694	631.001343	0.77604175	631.001343	0.78392935	631.001343	0.77119148	631.001343	0.77516878	631.001343	0.75582123	631.001343	0.69368887	
630.009522	0.80543351	630.009522	0.77890313	630.009522	0.78629059	630.009522	0.77566743	630.009522	0.77544475	630.009522	0.75794947	630.009522	0.69620103	
629.017456	0.80289441	629.017456	0.78061307	629.017456	0.78687984	629.017456	0.7742424	629.017456	0.77741987	629.017456	0.75962561	629.017456	0.697707	
627.988281	0.79973155	627.988281	0.77906913	627.988281	0.78642589	627.988281	0.77403301	627.988281	0.77496791	627.988281	0.75526905	627.988281	0.69388455	
626.995728	0.79818535	626.995728	0.7739163	626.995728	0.77844143	626.995728	0.76736826	626.995728	0.76844466	626.995728	0.74940431	626.995728	0.68908978	
626.002808	0.78547591	626.002808	0.76453632	626.002808	0.76788479	626.002808	0.75776494	626.002808	0.75779295	626.002808	0.74084473	626.002808	0.68025208	
625.009583	0.77612925	625.009583	0.75110376	625.009583	0.76102078	625.009583	0.74690229	625.009583	0.74751085	625.009583	0.72962314	625.009583	0.67230296	
624.016113	0.76392019	624.016113	0.7389102	624.016113	0.7442559	624.016113	0.733217	624.016113	0.73633343	624.016113	0.71843588	624.016113	0.66132408	

5 PPM BB Dye- 12.5 mg Evoqua 12x30 day 3														
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
636.98291	0.73439002	636.98291	0.7213515	636.98291	0.72233677	636.98291	0.71754086	636.98291	0.70818704	636.98291	0.70705766	636.98291	0.67494106
635.992737	0.75530911	635.992737	0.74441403	635.992737	0.74564445	635.992737	0.7375415	635.992737	0.72973502	635.992737	0.72604603	635.992737	0.6916644
635.002441	0.77259147	635.002441	0.76158512	635.002441	0.76101023	635.002441	0.75504595	635.002441	0.74833727	635.002441	0.74698049	635.002441	0.7099393
634.011719	0.78849661	634.011719	0.77711964	634.011719	0.77690315	634.011719	0.7666797	634.011719	0.76356971	634.011719	0.76090121	634.011719	0.72411299
632.98407	0.80172747	632.98407	0.78957564	632.98407	0.79242802	632.98407	0.78204453	632.98407	0.77648354	632.98407	0.7721166	632.98407	0.73550367
631.992859	0.81192929	631.992859	0.79821426	631.992859	0.79905856	631.992859	0.79208261	631.992859	0.78559476	631.992859	0.78342801	631.992859	0.74472886
631.001343	0.81808204	631.001343	0.8046447	631.001343	0.80619723	631.001343	0.7959429	631.001343	0.78814435	631.001343	0.7902562	631.001343	0.74790853
630.009522	0.82305586	630.009522	0.80653799	630.009522	0.80690628	630.009522	0.80089939	630.009522	0.79415268	630.009522	0.79292083	630.009522	0.75034797
629.017456	0.82168716	629.017456	0.80952877	629.017456	0.80777335	629.017456	0.80140317	629.017456	0.79532248	629.017456	0.79694533	629.017456	0.75388819
627.988281	0.81930345	627.988281	0.80719763	627.988281	0.80454838	627.988281	0.79622406	627.988281	0.79042435	627.988281	0.78888673	627.988281	0.74952716
626.995728	0.81387919	626.995728	0.80105823	626.995728	0.80068934	626.995728	0.79284716	626.995728	0.78574187	626.995728	0.78209835	626.995728	0.74551165
626.002808	0.80443865	626.002808	0.79201496	626.002808	0.78994149	626.002808	0.78283292	626.002808	0.7753399	626.002808	0.77249396	626.002808	0.73473579
625.009583	0.79572082	625.009583	0.78066582	625.009583	0.77942693	625.009583	0.77185512	625.009583	0.76988524	625.009583	0.76483178	625.009583	0.7239266
624.016113	0.780536	624.016113	0.76791143	624.016113	0.76552916	624.016113	0.75874436	624.016113	0.75224173	624.016113	0.75089574	624.016113	0.71342957

5 PPM BB Dye- 6 mg Evoqua 12x30 day 3													
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
636.98291	0.73676366	636.98291	0.70904195	636.98291	0.71527034	636.98291	0.69207484	636.98291	0.72249091	636.98291	0.71024597	636.98291	0.69543469
635.992737	0.75970918	635.992737	0.72763521	635.992737	0.73582476	635.992737	0.70939857	635.992737	0.74479628	635.992737	0.73251706	635.992737	0.71735925
635.002441	0.77953214	635.002441	0.74792737	635.002441	0.75798744	635.002441	0.72971779	635.002441	0.76116622	635.002441	0.75153297	635.002441	0.73628742
634.011719	0.79246235	634.011719	0.76425827	634.011719	0.76980543	634.011719	0.74357498	634.011719	0.77515787	634.011719	0.76513535	634.011719	0.74820429
632.98407	0.80400616	632.98407	0.77576661	632.98407	0.78411073	632.98407	0.75471914	632.98407	0.78913456	632.98407	0.77992886	632.98407	0.75999379
631.992859	0.81119645	631.992859	0.7848224	631.992859	0.79457915	631.992859	0.7637431	631.992859	0.79888147	631.992859	0.78776801	631.992859	0.7703265
631.001343	0.82029796	631.001343	0.78810376	631.001343	0.80001509	631.001343	0.77007067	631.001343	0.80567926	631.001343	0.79604459	631.001343	0.77285719
630.009522	0.82362646	630.009522	0.79586291	630.009522	0.80477119	630.009522	0.77527022	630.009522	0.80945385	630.009522	0.79666227	630.009522	0.78001875
629.017456	0.82161957	629.017456	0.79458493	629.017456	0.80413556	629.017456	0.77361834	629.017456	0.80960983	629.017456	0.79731441	629.017456	0.77858347
627.988281	0.81869865	627.988281	0.79111934	627.988281	0.80085468	627.988281	0.77086955	627.988281	0.80493677	627.988281	0.79487836	627.988281	0.7777276
626.995728	0.8172968	626.995728	0.78404903	626.995728	0.79519898	626.995728	0.76580983	626.995728	0.80076337	626.995728	0.78720522	626.995728	0.77043909
626.002808	0.80668777	626.002808	0.77922285	626.002808	0.78726149	626.002808	0.75778002	626.002808	0.79065329	626.002808	0.77945769	626.002808	0.76412159
625.009583	0.79683358	625.009583	0.76455408	625.009583	0.77548164	625.009583	0.74577206	625.009583	0.77921909	625.009583	0.76745403	625.009583	0.75374526
624.016113	0.78412128	624.016113	0.75539899	624.016113	0.76211339	624.016113	0.73518938	624.016113	0.76375729	624.016113	0.75553113	624.016113	0.74034232

5 PPM MB Dye- 18 mg Modified Evoqua 12x30 day 3														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
668.007996	1.0041436	668.007996	0.8819685	668.007996	0.75937599	668.007996	0.59240103	668.007996	0.38540307	668.007996	0.18727543	668.007996	0.00456231	
666.990479	1.01444566	666.990479	0.88593352	666.990479	0.76770788	666.990479	0.60184717	666.990479	0.39094001	666.990479	0.18972692	666.990479	0.00415154	
666.009155	1.02342331	666.009155	0.89672852	666.009155	0.77555794	666.009155	0.60610563	666.009155	0.39491627	666.009155	0.19002456	666.009155	0.00378257	
664.991089	1.02791154	664.991089	0.90090472	664.991089	0.77868313	664.991089	0.60662741	664.991089	0.39543468	664.991089	0.19103053	664.991089	0.00380198	
664.009033	1.02800179	664.009033	0.90132141	664.009033	0.7773639	664.009033	0.60752821	664.009033	0.39624542	664.009033	0.19076349	664.009033	0.0036944	
662.990418	1.03103077	662.990418	0.89736319	662.990418	0.777282	662.990418	0.60589188	662.990418	0.39456096	662.990418	0.18992826	662.990418	0.00348737	
662.007752	1.01874828	662.007752	0.88951051	662.007752	0.77389944	662.007752	0.60161144	662.007752	0.39214116	662.007752	0.18876121	662.007752	0.00315234	
660.988525	1.01802158	660.988525	0.88747877	660.988525	0.76763618	660.988525	0.59764373	660.988525	0.38732246	660.988525	0.18701629	660.988525	0.00316483	
660.005249	1.00550783	660.005249	0.87979013	660.005249	0.7601797	660.005249	0.59443921	660.005249	0.38431704	660.005249	0.18622877	660.005249	0.00305877	
658.985413	0.99860478	658.985413	0.86916012	658.985413	0.75009531	658.985413	0.58727068	658.985413	0.38066834	658.985413	0.18437821	658.985413	0.00304899	
658.001709	0.99059248	658.001709	0.86012393	658.001709	0.74231678	658.001709	0.58110803	658.001709	0.3762916	658.001709	0.18219404	658.001709	0.00294653	

5 PPM MB Dye- 12.5 mg Modified Evoqua 12x30 day 3														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
668.007996	1.02007294	668.007996	0.91294652	668.007996	0.82852143	668.007996	0.65118027	668.007996	0.49446783	668.007996	0.31151748	668.007996	0.01705756	
666.990479	1.03036892	666.990479	0.9269768	666.990479	0.84211725	666.990479	0.65965551	666.990479	0.50087977	666.990479	0.31467527	666.990479	0.01617199	
666.009155	1.03848469	666.009155	0.93707156	666.009155	0.84774822	666.009155	0.66669035	666.009155	0.50420958	666.009155	0.3169122	666.009155	0.01646321	
664.991089	1.03724456	664.991089	0.94070488	664.991089	0.85230941	664.991089	0.66606575	664.991089	0.50810927	664.991089	0.3178353	664.991089	0.01648827	
664.009033	1.0397743	664.009033	0.94212657	664.009033	0.85122716	664.009033	0.66990125	664.009033	0.50800157	664.009033	0.31879899	664.009033	0.01669672	
662.990418	1.0440799	662.990418	0.93889761	662.990418	0.8521508	662.990418	0.66669345	662.990418	0.50637233	662.990418	0.31756404	662.990418	0.01643073	
662.007752	1.03959978	662.007752	0.93568713	662.007752	0.84701717	662.007752	0.66378009	662.007752	0.50248945	662.007752	0.31661853	662.007752	0.01645407	
660.988525	1.03857637	660.988525	0.92456621	660.988525	0.8425346	660.988525	0.66015226	660.988525	0.49920279	660.988525	0.31312752	660.988525	0.01627193	
660.005249	1.02527535	660.005249	0.91793913	660.005249	0.83302033	660.005249	0.65461701	660.005249	0.49340323	660.005249	0.31029716	660.005249	0.01703513	
658.985413	1.0145483	658.985413	0.9097997	658.985413	0.82596368	658.985413	0.64570081	658.985413	0.48912725	658.985413	0.3084887	658.985413	0.01608272	
658.001709	1.00244141	658.001709	0.89889348	658.001709	0.81232506	658.001709	0.63858855	658.001709	0.48238188	658.001709	0.30375326	658.001709	0.01679336	

5 PPM MB Dye- 6 mg Modified Evoqua 12x30 day 3														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
668.988831	0.98859912	668.988831	0.9624961	668.988831	0.91506934	668.988831	0.8457163	668.988831	0.7692129	668.988831	0.66013056	668.988831	0.38906217	
668.007996	1.01028132	668.007996	0.98059285	668.007996	0.92984527	668.007996	0.86301678	668.007996	0.77872747	668.007996	0.67492139	668.007996	0.39537007	
666.990479	1.01618588	666.990479	0.99507654	666.990479	0.94864535	666.990479	0.87551361	666.990479	0.7909013	666.990479	0.68072277	666.990479	0.40030962	
666.009155	1.02306318	666.009155	1.0047313	666.009155	0.94684106	666.009155	0.8764621	666.009155	0.79724705	666.009155	0.68633992	666.009155	0.40471879	
664.991089	1.0308305	664.991089	1.00303841	664.991089	0.95211554	664.991089	0.88862705	664.991089	0.79938775	664.991089	0.69048405	664.991089	0.4054378	
664.009033	1.03076971	664.009033	1.01108038	664.009033	0.95715421	664.009033	0.88817263	664.009033	0.79955047	664.009033	0.69257188	664.009033	0.4065342	
662.990418	1.03022373	662.990418	1.00234842	662.990418	0.95481056	662.990418	0.8822555	662.990418	0.79815328	662.990418	0.6874736	662.990418	0.40564999	
662.007752	1.01927316	662.007752	1.00327575	662.007752	0.94951814	662.007752	0.87816173	662.007752	0.7942788	662.007752	0.68365753	662.007752	0.40468535	
660.988525	1.01692653	660.988525	0.99499667	660.988525	0.9391495	660.988525	0.87378323	660.988525	0.79024792	660.988525	0.6789487	660.988525	0.40031439	
660.005249	1.00842333	660.005249	0.98320973	660.005249	0.9322269	660.005249	0.86226022	660.005249	0.78079242	660.005249	0.67246151	660.005249	0.39830411	
658.985413	0.99949122	658.985413	0.97550523	658.985413	0.92285019	658.985413	0.85588616	658.985413	0.77329677	658.985413	0.66709232	658.985413	0.39407212	

5 PPM BB Dye- 18 mg Modified Evoqua 12x30 day 5												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
634.005676	0.76106119	634.005676	0.75764799	634.005676	0.75802684	634.005676	0.75030458	634.005676	0.746144	634.005676	0.72596669	634.017578	0.70323199
633.014465	0.77478695	633.014465	0.7709347	633.014465	0.76927435	633.014465	0.76507425	633.014465	0.76050901	633.014465	0.73797631	632.989807	0.71664274
631.986328	0.78454816	631.986328	0.78026581	631.986328	0.77916539	631.986328	0.77362043	631.986328	0.76770049	631.986328	0.74898398	631.998474	0.72415763
630.994507	0.78769594	630.994507	0.79017341	630.994507	0.78569037	630.994507	0.78132898	630.994507	0.77235848	630.994507	0.75333565	631.006836	0.73184174
630.002564	0.79014236	630.002564	0.79077339	630.002564	0.78907168	630.002564	0.78281027	630.002564	0.77564865	630.002564	0.7560485	630.014893	0.72895128
629.010193	0.79547501	629.010193	0.79054081	629.010193	0.7886036	629.010193	0.78471845	629.010193	0.77688748	629.010193	0.7561174	628.986023	0.73226422
628.017578	0.79145318	628.017578	0.78844464	628.017578	0.78657413	628.017578	0.77926433	628.017578	0.7723273	628.017578	0.75536442	627.993469	0.72881371
626.987976	0.78412861	626.987976	0.7854327	626.987976	0.78240931	626.987976	0.77495539	626.987976	0.76617372	626.987976	0.74688995	627.000794	0.72264564
625.994873	0.77583122	625.994873	0.77429158	625.994873	0.76953954	625.994873	0.76121587	625.994873	0.75611603	625.994873	0.74020672	626.007752	0.71249473
625.001343	0.76508307	625.001343	0.76181263	625.001343	0.75773162	625.001343	0.75387985	625.001343	0.74647695	625.001343	0.7283808	625.014465	0.70126379
624.00769	0.7516548	624.00769	0.74822664	624.00769	0.74726695	624.00769	0.73895586	624.00769	0.73526132	624.00769	0.71724916	623.98407	0.6908502
5 PPM BB Dye- 12.5mg Modified Evoqua 12x30 day 5												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
634.996582	0.75129813	634.996582	0.74171752	634.996582	0.74374294	634.996582	0.72744364	634.996582	0.73004723	634.996582	0.68612885	635.008423	0.71345168
634.005676	0.76330882	634.005676	0.75993997	634.005676	0.75642633	634.005676	0.74009967	634.005676	0.74620992	634.005676	0.69963735	634.017578	0.72764504
633.014465	0.77696151	633.014465	0.77250791	633.014465	0.77030033	633.014465	0.75182712	633.014465	0.75776076	633.014465	0.71076292	632.989807	0.73668998
631.986328	0.78535479	631.986328	0.78071016	631.986328	0.7795698	631.986328	0.76300061	631.986328	0.76776391	631.986328	0.72100919	631.998474	0.74872446
630.994507	0.79231787	630.994507	0.78695327	630.994507	0.78353345	630.994507	0.76870799	630.994507	0.77459592	630.994507	0.72524971	631.006836	0.75327671
630.002564	0.79421163	630.002564	0.79378605	630.002564	0.7878353	630.002564	0.77498317	630.002564	0.77738655	630.002564	0.72919643	630.014893	0.75770009
629.010193	0.79265159	629.010193	0.79218918	629.010193	0.7888068	629.010193	0.77033854	629.010193	0.77905905	629.010193	0.72829199	628.986023	0.75869781
628.017578	0.79432708	628.017578	0.78837937	628.017578	0.78531265	628.017578	0.76817358	628.017578	0.77489394	628.017578	0.72446191	627.993469	0.75584513
626.987976	0.78624064	626.987976	0.78297913	626.987976	0.77745575	626.987976	0.76475835	626.987976	0.76767635	626.987976	0.72118503	627.000794	0.75017506
625.994873	0.77484655	625.994873	0.77245927	625.994873	0.77068692	625.994873	0.75270104	625.994873	0.75783044	625.994873	0.71194083	626.007752	0.73888057
625.001343	0.76562381	625.001343	0.76363236	625.001343	0.76042682	625.001343	0.74139029	625.001343	0.74836206	625.001343	0.70169711	625.014465	0.73030853
624.00769	0.75557315	624.00769	0.75187975	624.00769	0.74688005	624.00769	0.7301743	624.00769	0.73557365	624.00769	0.68973792	623.98407	0.71671152
5 PPM BB Dye- 6 mg Modified Evoqua 12x30 day 5												
Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs	Wavelength (nm)	Abs
634.996582	0.75273699	634.996582	0.74883133	634.996582	0.75081152	634.996582	0.76088804	634.996582	0.72645485	634.996582	0.73610979	635.008423	0.7399745
634.005676	0.76430166	634.005676	0.76249278	634.005676	0.76677066	634.005676	0.77725488	634.005676	0.74269474	634.005676	0.75107414	634.017578	0.75226194
633.014465	0.77541602	633.014465	0.77588928	633.014465	0.77850562	633.014465	0.78611821	633.014465	0.75518918	633.014465	0.76028007	632.989807	0.76289988
631.986328	0.7881915	631.986328	0.78666443	631.986328	0.78463113	631.986328	0.80176473	631.986328	0.76496035	631.986328	0.7721734	631.998474	0.77479148
630.994507	0.796556	630.994507	0.79160738	630.994507	0.79467112	630.994507	0.80416912	630.994507	0.77122712	630.994507	0.78080213	631.006836	0.77938622
630.002564	0.7962572	630.002564	0.79705065	630.002564	0.79684508	630.002564	0.8048318	630.002564	0.77269876	630.002564	0.78179413	630.014893	0.78391063
629.010193	0.80069721	629.010193	0.79744935	629.010193	0.79822493	629.010193	0.80646694	629.010193	0.77374136	629.010193	0.78447086	628.986023	0.78308153
628.017578	0.79587036	628.017578	0.79200113	628.017578	0.79766321	628.017578	0.80487794	628.017578	0.77382708	628.017578	0.77856272	627.993469	0.78074896
626.987976	0.78953999	626.987976	0.78845447	626.987976	0.7889505	626.987976	0.79879069	626.987976	0.76514775	626.987976	0.77375287	627.000794	0.77665365
625.994873	0.77836084	625.994873	0.77567345	625.994873	0.77778208	625.994873	0.7869041	625.994873	0.75625259	625.994873	0.76445079	626.007752	0.7648235
625.001343	0.76940924	625.001343	0.76610678	625.001343	0.76854169	625.001343	0.77474791	625.001343	0.74562019	625.001343	0.75087172	625.014465	0.75493324
624.00769	0.75604302	624.00769	0.75378293	624.00769	0.75456208	624.00769	0.7629723	624.00769	0.73279214	624.00769	0.7402662	623.98407	0.74624938

5 PPM MB Dye- 18 mg Modified Evoqua 12x30 day 5														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
670.008057	0.95284009	670.008057	0.83525711	670.008057	0.72025085	670.008057	0.55297208	670.008057	0.38117167	670.008057	0.17239335	670.015564	-0.0056493	
668.991028	0.96823877	668.991028	0.84888107	668.991028	0.73679191	668.991028	0.56372476	668.991028	0.39049098	668.991028	0.17480972	668.998657	-0.0047601	
668.010071	0.98682523	668.010071	0.86996382	668.010071	0.74868441	668.010071	0.57646686	668.010071	0.39701247	668.010071	0.17900243	668.0177	-0.0054426	
666.99231	1.00057638	666.99231	0.87828851	666.99231	0.75770557	666.99231	0.58298737	666.99231	0.40086854	666.99231	0.18123049	667.000122	-0.0073203	
666.010681	1.00857842	666.010681	0.88476521	666.010681	0.76479679	666.010681	0.58583313	666.010681	0.4042998	666.010681	0.18188231	665.9823	-0.0058516	
664.992371	1.01088476	664.992371	0.89408636	664.992371	0.76738524	664.992371	0.58694369	664.992371	0.40572184	664.992371	0.18272187	665.000488	-0.0063969	
664.010132	1.00792432	664.010132	0.89103669	664.010132	0.77003336	664.010132	0.58764893	664.010132	0.40588689	664.010132	0.18357009	663.981995	-0.0060046	
662.991211	1.0077889	662.991211	0.88847709	662.991211	0.76658654	662.991211	0.5890004	662.991211	0.40427792	662.991211	0.18178466	662.999573	-0.0061523	
662.008362	1.00682437	662.008362	0.88669229	662.008362	0.76684648	662.008362	0.58444107	662.008362	0.40284368	662.008362	0.1812149	662.016846	-0.0064514	
660.988892	0.9999634	660.988892	0.87803108	660.988892	0.75863439	660.988892	0.57886946	660.988892	0.39949629	660.988892	0.1798384	660.997437	-0.0069318	
660.005432	0.98676193	660.005432	0.87355024	660.005432	0.75058252	660.005432	0.57301629	660.005432	0.39506719	660.005432	0.17799757	660.014099	-0.0068993	
5 PPM MB Dye- 12.5 mg Modified Evoqua 12x30 day 5														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
668.991028	0.96981031	668.991028	0.89513403	668.991028	0.78252792	668.991028	0.6815632	668.991028	0.51073432	668.991028	0.31374291	668.998657	0.00851479	
668.010071	0.99345207	668.010071	0.91345233	668.010071	0.80189633	668.010071	0.69614393	668.010071	0.51675695	668.010071	0.3196142	668.0177	0.00884836	
666.99231	1.00389719	666.99231	0.92444432	666.99231	0.80967796	666.99231	0.70037287	666.99231	0.5225457	666.99231	0.32310715	667.000122	0.00907768	
666.010681	1.00683117	666.010681	0.93205267	666.010681	0.8169331	666.010681	0.70503438	666.010681	0.52685565	666.010681	0.32640252	665.9823	0.00828642	
664.992371	1.01060057	664.992371	0.93689382	664.992371	0.81538475	664.992371	0.71217453	664.992371	0.53069395	664.992371	0.3267844	665.000488	0.00755015	
664.010132	1.0157131	664.010132	0.93493539	664.010132	0.82487834	664.010132	0.71000755	664.010132	0.53241587	664.010132	0.32724676	663.981995	0.00845542	
662.991211	1.01151347	662.991211	0.92777056	662.991211	0.82166052	662.991211	0.71027583	662.991211	0.52942574	662.991211	0.32656962	662.999573	0.00741684	
662.008362	1.01133072	662.008362	0.93097407	662.008362	0.81152165	662.008362	0.70560843	662.008362	0.52726763	662.008362	0.32523957	662.016846	0.00861142	
660.988892	1.00390446	660.988892	0.92002434	660.988892	0.80558211	660.988892	0.70237696	660.988892	0.52157497	660.988892	0.32098192	660.997437	0.0078193	
660.005432	0.99027359	660.005432	0.91402805	660.005432	0.8015238	660.005432	0.69650555	660.005432	0.51695293	660.005432	0.31847078	660.014099	0.00801069	
5 PPM MB Dye- 6 mg Modified Evoqua 12x30 day 5														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
668.010071	0.99063241	668.010071	0.96278059	668.010071	0.90148556	668.010071	0.8378132	668.010071	0.75957274	668.010071	0.64043856	668.0177	0.35741416	
666.99231	0.99629867	666.99231	0.97215861	666.99231	0.91628933	666.99231	0.84504151	666.99231	0.76612115	666.99231	0.64862257	667.000122	0.36141789	
666.010681	1.01016915	666.010681	0.98059976	666.010681	0.91988063	666.010681	0.85294163	666.010681	0.77615196	666.010681	0.65279901	665.9823	0.36536807	
664.992371	1.00739527	664.992371	0.98290575	664.992371	0.92877543	664.992371	0.85931957	664.992371	0.77418178	664.992371	0.65584546	665.000488	0.36711869	
664.010132	1.0103972	664.010132	0.98628014	664.010132	0.9310782	664.010132	0.85700697	664.010132	0.77336419	664.010132	0.65710378	663.981995	0.36777565	
662.991211	1.01533842	662.991211	0.97653013	662.991211	0.92044216	662.991211	0.85593885	662.991211	0.77399641	662.991211	0.65662307	662.999573	0.36437103	
662.008362	1.00295603	662.008362	0.97798902	662.008362	0.92122132	662.008362	0.85292447	662.008362	0.77251774	662.008362	0.64974338	662.016846	0.36443833	
660.988892	0.9979133	660.988892	0.97077674	660.988892	0.91368836	660.988892	0.84683228	660.988892	0.76361591	660.988892	0.64536214	660.997437	0.36252114	
660.005432	0.98937851	660.005432	0.95766568	660.005432	0.90562266	660.005432	0.83784777	660.005432	0.7563318	660.005432	0.64018416	660.014099	0.35909358	
658.985291	0.98197716	658.985291	0.95063835	658.985291	0.89476615	658.985291	0.8304916	658.985291	0.75010377	658.985291	0.63543129	658.994141	0.35536283	
658.001282	0.96768379	658.001282	0.94503552	658.001282	0.88538402	658.001282	0.81950438	658.001282	0.744344	658.001282	0.62852633	658.010254	0.35054424	

5 PPM BB Dye- 18 mg Modified Evoqua 12x30 day 7												
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
639.994873	0.6271376	639.994873	0.63791221	639.994873	0.63106757	639.994873	0.62994963	639.994873	0.61295509	639.994873	0.61076051	639.994873	0.55327439
638.015808	0.67503583	638.015808	0.69064826	638.015808	0.68717957	638.015808	0.68261272	638.015808	0.6623264	638.015808	0.66082197	638.015808	0.59750491
635.998901	0.71869123	635.998901	0.73474318	635.998901	0.72937965	635.998901	0.72696596	635.998901	0.70217371	635.998901	0.7042293	635.998901	0.63635802
634.017639	0.75009465	634.017639	0.76366115	634.017639	0.76420057	634.017639	0.76239246	634.017639	0.73398536	634.017639	0.73556525	634.017639	0.66793048
631.998535	0.77604395	631.998535	0.78700799	631.998535	0.78692681	631.998535	0.78725606	631.998535	0.75890636	631.998535	0.76143205	631.998535	0.68604559
630.014954	0.78487688	630.014954	0.79754472	630.014954	0.79681242	630.014954	0.79531831	630.014954	0.76779997	630.014954	0.77031231	630.014954	0.69425708
627.99353	0.78340268	627.99353	0.79662555	627.99353	0.79441696	627.99353	0.79548949	627.99353	0.76648402	627.99353	0.76816541	627.99353	0.69311851
626.007813	0.76854974	626.007813	0.78260726	626.007813	0.7806142	626.007813	0.77881622	626.007813	0.75489736	626.007813	0.75526047	626.007813	0.68218958
623.984131	0.74535441	623.984131	0.75872862	623.984131	0.75644535	623.984131	0.75314271	623.984131	0.72884768	623.984131	0.73287642	623.984131	0.66063619
621.996155	0.71501327	621.996155	0.72775453	621.996155	0.72331208	621.996155	0.72093016	621.996155	0.70158333	621.996155	0.70090485	621.996155	0.63328338
620.00708	0.67965692	620.00708	0.69129884	620.00708	0.68824571	620.00708	0.68352628	620.00708	0.66416174	620.00708	0.66622126	620.00708	0.60133326
5 PPM BB Dye- 12.5 mg Modified Evoqua 12x30 day 7												
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
639.994873	0.65440059	639.994873	0.64654535	639.994873	0.65419114	639.994873	0.6542691	639.994873	0.63268012	639.994873	0.62439466	639.994873	0.63234031
638.015808	0.70478076	638.015808	0.69894904	638.015808	0.70998132	638.015808	0.70544666	638.015808	0.682136	638.015808	0.67432725	638.015808	0.68233955
635.998901	0.75041062	635.998901	0.74315882	635.998901	0.75238967	635.998901	0.75461775	635.998901	0.7263366	635.998901	0.71879977	635.998901	0.7254653
634.017639	0.78084517	634.017639	0.77695608	634.017639	0.7895509	634.017639	0.78856105	634.017639	0.7600984	634.017639	0.75244379	634.017639	0.75881219
631.998535	0.80651939	631.998535	0.80243194	631.998535	0.81419104	631.998535	0.812024	631.998535	0.78279787	631.998535	0.77772498	631.998535	0.78312683
630.014954	0.81751895	630.014954	0.80872846	630.014954	0.82070988	630.014954	0.82119662	630.014954	0.7930057	630.014954	0.7872346	630.014954	0.79399824
627.99353	0.81604397	627.99353	0.81248152	627.99353	0.8209886	627.99353	0.8213014	627.99353	0.78982735	627.99353	0.78606677	627.99353	0.79404408
626.007813	0.79997814	626.007813	0.79364997	626.007813	0.80612719	626.007813	0.80753988	626.007813	0.77884471	626.007813	0.77058017	626.007813	0.77805793
623.984131	0.77557641	623.984131	0.76918882	623.984131	0.78440201	623.984131	0.78137368	623.984131	0.7534501	623.984131	0.74598289	623.984131	0.75436848
621.996155	0.74579233	621.996155	0.738648	621.996155	0.74480993	621.996155	0.74736696	621.996155	0.72315699	621.996155	0.71491623	621.996155	0.72111464
620.00708	0.70910394	620.00708	0.70115185	620.00708	0.70616978	620.00708	0.70955443	620.00708	0.68762487	620.00708	0.67568821	620.00708	0.68508422
5 PPM BB Dye- 6 mg Modified Evoqua 12x30 day 7												
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs
638.015808	0.69874787	638.015808	0.69400787	638.015808	0.7049278	638.015808	0.69967103	638.015808	0.68338931	638.015808	0.67302305	638.015808	0.66653341
635.998901	0.74364716	635.998901	0.74138224	635.998901	0.74920017	635.998901	0.74713671	635.998901	0.72538191	635.998901	0.72155422	635.998901	0.70591766
634.017639	0.77714306	634.017639	0.77353179	634.017639	0.78477639	634.017639	0.78037739	634.017639	0.75867158	634.017639	0.75504208	634.017639	0.74004608
631.998535	0.80094731	631.998535	0.79641849	631.998535	0.80983311	631.998535	0.80422848	631.998535	0.78232986	631.998535	0.78005189	631.998535	0.76158559
630.014954	0.80836767	630.014954	0.81077635	630.014954	0.81652027	630.014954	0.81846672	630.014954	0.79181409	630.014954	0.78744137	630.014954	0.7718612
627.99353	0.81021577	627.99353	0.80863208	627.99353	0.81519395	627.99353	0.81272829	627.99353	0.79133481	627.99353	0.79048336	627.99353	0.7698375
626.007813	0.79618466	626.007813	0.79429412	626.007813	0.80393767	626.007813	0.79899937	626.007813	0.77471644	626.007813	0.77092701	626.007813	0.75462705
623.984131	0.77025288	623.984131	0.76858866	623.984131	0.77502298	623.984131	0.77048099	623.984131	0.75359458	623.984131	0.7477228	623.984131	0.7336548
621.996155	0.74017733	621.996155	0.73647147	621.996155	0.74391925	621.996155	0.73897368	621.996155	0.72194499	621.996155	0.71591526	621.996155	0.70338041
620.00708	0.70224971	620.00708	0.70114219	620.00708	0.70705456	620.00708	0.70189285	620.00708	0.68782508	620.00708	0.67945486	620.00708	0.66857547
618.016907	0.66218835	618.016907	0.65847123	618.016907	0.66559076	618.016907	0.65857702	618.016907	0.64877647	618.016907	0.63754547	618.016907	0.62830812

5 PPM MB Dye- 18 mg Modified Evoqua 12x30 day 7														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
674.00769	0.80660015	674.00769	0.77386808	674.00769	0.66363847	674.00769	0.52958685	674.00769	0.34788215	674.00769	0.15712434	674.00769	-0.0012035	
672.012329	0.87624151	672.012329	0.84088218	672.012329	0.72334892	672.012329	0.57473707	672.012329	0.3791101	672.012329	0.17247787	672.012329	-0.0004697	
670.015625	0.9250676	670.015625	0.88734794	670.015625	0.7702716	670.015625	0.61235738	670.015625	0.40170658	670.015625	0.18526679	670.015625	-0.000387	
668.017761	0.96272349	668.017761	0.9227041	668.017761	0.80048269	668.017761	0.63626951	668.017761	0.41789371	668.017761	0.19285306	668.017761	-0.000972	
665.982361	0.98133862	665.982361	0.9470681	665.982361	0.81433356	665.982361	0.65164167	665.982361	0.42718902	665.982361	0.19725555	665.982361	-0.0022657	
663.982056	0.9925065	663.982056	0.94956189	663.982056	0.81951422	663.982056	0.65396005	663.982056	0.43051896	663.982056	0.19914903	663.982056	-0.0020992	
662.016907	0.98809636	662.016907	0.94198519	662.016907	0.81730348	662.016907	0.65025944	662.016907	0.4258185	662.016907	0.19699968	662.016907	-0.0022902	
660.01416	0.96831757	660.01416	0.92372173	660.01416	0.8019138	660.01416	0.63927984	660.01416	0.41981375	660.01416	0.19217019	660.01416	-0.0022184	
658.010315	0.94935501	658.010315	0.90542942	658.010315	0.78649694	658.010315	0.62519068	658.010315	0.41028887	658.010315	0.18799676	658.010315	-0.0022487	
656.005188	0.92065889	656.005188	0.88105625	656.005188	0.76268661	656.005188	0.60962224	656.005188	0.39882889	656.005188	0.18316071	656.005188	-0.002266	
653.998901	0.8957023	653.998901	0.8575756	653.998901	0.73637825	653.998901	0.58895719	653.998901	0.38539398	653.998901	0.1775481	653.998901	-0.0027711	
5 PPM MB Dye- 12.5 mg Modified Evoqua 12x30 day 7														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
674.00769	0.83089864	674.00769	0.79706955	674.00769	0.71702671	674.00769	0.60551476	674.00769	0.48528501	674.00769	0.33839595	674.00769	0.04890711	
672.012329	0.899544	672.012329	0.85906911	672.012329	0.78374892	672.012329	0.66077226	672.012329	0.52586901	672.012329	0.36860397	672.012329	0.05368418	
670.015625	0.95427883	670.015625	0.9103235	670.015625	0.83280176	670.015625	0.70449436	670.015625	0.55567926	670.015625	0.39187494	670.015625	0.05638888	
668.017761	0.99212652	668.017761	0.95272166	668.017761	0.86068821	668.017761	0.72916919	668.017761	0.57997847	668.017761	0.41069242	668.017761	0.05936156	
665.982361	1.01289952	665.982361	0.96637833	665.982361	0.88239706	665.982361	0.74751854	665.982361	0.59215218	665.982361	0.41686052	665.982361	0.05966212	
663.982056	1.02274072	663.982056	0.97596371	663.982056	0.89062899	663.982056	0.75183243	663.982056	0.59648967	663.982056	0.42032212	663.982056	0.06026324	
662.016907	1.0160172	662.016907	0.96981108	662.016907	0.8799969	662.016907	0.74600899	662.016907	0.59229988	662.016907	0.41710705	662.016907	0.06039658	
660.01416	0.99426329	660.01416	0.95380396	660.01416	0.8646853	660.01416	0.73467034	660.01416	0.58243698	660.01416	0.40969312	660.01416	0.0584933	
658.010315	0.97365844	658.010315	0.9359979	658.010315	0.84726411	658.010315	0.71713638	658.010315	0.56964999	658.010315	0.40004131	658.010315	0.05788436	
656.005188	0.9505617	656.005188	0.91187328	656.005188	0.82403219	656.005188	0.69832295	656.005188	0.55460733	656.005188	0.38746169	656.005188	0.05690102	
653.998901	0.91917473	653.998901	0.8844071	653.998901	0.7975294	653.998901	0.67743701	653.998901	0.53492641	653.998901	0.37715691	653.998901	0.05544824	
5 PPM MB Dye- 6 mg Modified Evoqua 12x30 day 7														
Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	Wavelength (	Abs	
674.00769	0.85247302	674.00769	0.81265056	674.00769	0.75253302	674.00769	0.68178761	674.00769	0.61054754	674.00769	0.49362192	674.00769	0.27294233	
672.012329	0.92293739	672.012329	0.87815464	672.012329	0.81539947	672.012329	0.73971009	672.012329	0.66068411	672.012329	0.53719485	672.012329	0.29539305	
670.015625	0.97320998	670.015625	0.9291383	670.015625	0.8676396	670.015625	0.7888093	670.015625	0.70221663	670.015625	0.57088822	670.015625	0.31258076	
668.017761	1.02134013	668.017761	0.97279048	668.017761	0.89836675	668.017761	0.82450897	668.017761	0.73103106	668.017761	0.5941239	668.017761	0.32660124	
665.982361	1.0392648	665.982361	0.99447495	665.982361	0.92415828	665.982361	0.8434025	665.982361	0.74670202	665.982361	0.60677058	665.982361	0.33378914	
663.982056	1.04263353	663.982056	0.99752551	663.982056	0.92379421	663.982056	0.84434354	663.982056	0.74986923	663.982056	0.61188656	663.982056	0.33567551	
662.016907	1.03934407	662.016907	0.99248451	662.016907	0.91998583	662.016907	0.84109688	662.016907	0.74471611	662.016907	0.60649794	662.016907	0.33291346	
660.01416	1.02251673	660.01416	0.97207409	660.01416	0.90361691	660.01416	0.82545501	660.01416	0.7314021	660.01416	0.59589309	660.01416	0.32878223	
658.010315	0.99895531	658.010315	0.95397961	658.010315	0.88502401	658.010315	0.80333096	658.010315	0.71660101	658.010315	0.58426058	658.010315	0.32277226	
656.005188	0.9741196	656.005188	0.93142164	656.005188	0.86049587	656.005188	0.78400445	656.005188	0.69717342	656.005188	0.56615412	656.005188	0.31506699	
653.998901	0.94788349	653.998901	0.89384031	653.998901	0.8353197	653.998901	0.7597242	653.998901	0.67602444	653.998901	0.55096465	653.998901	0.30345738	

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14. ABSTRACT Granular activated carbon and carbon nanofiber samples were tested as is and electrochemically modified to determine the effect on adsorption. An electrochemical cell was used to modify the carbon samples. The samples were then used in bench bottle tests with 2,4-dinitrotoluene (DNT), brilliant blue (BB) dye, and methylene blue (MB) dye solutions and sampled over time intervals. An ultraviolet–visible spectrophotometer was used to analyze the results of the bottle bench tests. The results indicated that electrochemically modified coal-based carbons' adsorption were improved 25% over the adsorption of the as is carbon samples prior to modification. The electrochemical modification increased adsorption of contaminants (DNT, BB, and MB) of the three coal-based carbons at two levels of carbon concentration (25 mg and 12.5 mg). The modified carbon nanofiber showed no change in the pilot BB dye adsorption study; therefore, only scanning electron microscope (SEM) images were taken and no further BB and MB dye or DNT studies were pursued. The modified coconut shell carbon adsorption results varied in the initial DNT studies. Further adsorption studies were conducted with coconut-based carbon after electrochemical modification. The results showed that the electrochemical treatment degraded the adsorption of the coconut-based carbon below 50% of the original, as is carbon adsorption. The study further revealed over 7 days after the modification of the coconut carbon, it slowly began to regain its original adsorption performance.					
15. SUBJECT TERMS Electrochemical modification, electrochemical cell, bench bottle test, granular activated carbon (GAC), Brilliant Blue, Methylene Blue, Toluene, 2,4-Dinitrotoluene, DNT, biodegradable, adsorbent					
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